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HAZARDS STUDY OF LARGE SOLID PROPELLANT MOTORS (U)

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By: *Adolph B. Amster*

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Approved:

THOR L. SMITH, DIRECTOR
PROPULSION SCIENCES DIVISION

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ABSTRACT

Large rocket motors of conventional solid propellants present potential hazards in use situations. Sensitivity tests are evaluated in terms of their ability to predict the consequences of these hazards. It is shown that segments of large motors present only a fire hazard while being transported, whereas monoliths may explode. Otherwise both types present only fire hazards except that, when fully armed or when the upper liquid stages are being fueled or are already fueled, they must be considered as presenting an explosive hazard.

The applicability to large motors of the Armed Services Explosives Safety Board tentative criteria for hazard classification is discussed.

Suggestions are made for new tests and for additional basic research.

An extensive bibliography is included.

FOREWORD

Under the terms of NASA Contract NASr-49(05) the Propulsion Sciences Division of Stanford Research Institute has conducted a brief survey and analysis of existing and proposed methods for testing and classifying large rocket motors of conventional solid propellants with respect to their potential hazard in situations involving fire, drop, fragment, impact, nearby blast, and mechanical shock, but not including toxicity, fragmentation, and problems arising from sonic and nuclear hazards.

This report of the study is presented in several parts. Part One analyzes the circumstances which may cause such a motor to be exposed to hazard and predicts the results of this exposure. The prediction is developed from a synthesis and evaluation of experience, practical tests, and laboratory tests.

Part Two is a critique of the still tentative Armed Services Explosives Safety Board's (ASESB) Explosives Hazard Classification Procedure.

Part Three presents recommendations for the test necessary to provide an unambiguous hazard classification and for additional supporting research.

During the course of the study a number of reports, documents, etc., were examined, some cursorily, some in detail. Lest the effort be repeated by others, Part Four contains a list of the documents with some indication of the area considered. The list should not be considered complete; the field of interest given is merely a guide.

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PART ONE: CLASSIFICATION BASED UPON EXISTING TECHNOLOGY

I Introduction

On July 17, 1944, at Port Chicago, California, three and one-half million pounds of explosives in railroad cars and in the holds of a ship exploded.[1] Three hundred twenty persons were killed, 390 were injured, and property damage was estimated at $13,000,000. Among the injured were two persons 8 miles away; each lost the sight of an eye.

Approximately three weeks later a 20-kiloton atomic device was detonated over Hiroshima.[2] Equivalent to approximately 40 million pounds of TNT, it destroyed a 4.7-square-mile area, left 70,000 injured, and an equal number killed or missing. Assuming that the blast effect of an explosive is proportional to the cube root of its weight, this bomb was only 2-1/4 times as powerful as the Port Chicago explosion.

The basic motors now being considered for NASA/DOD missions are: a 156-in.-diameter segmented motor weighing 1,500,000 lb and a 260-in.-diameter segmented motor weighing 3,500,000 lb. The motors would be used in clusters of about four.[3] Restricting the calculations only to the blast effects, the consequences of the detonation of four of the larger motors may be predicted. The approximate results,[5] assuming 100% and 20% TNT equivalents, are presented in Fig. 1.*

For the milder case, at 9,000 feet the peak overpressure is 0.65 psi, the maximum exposure pressure recommended for inhabited buildings. Accordingly, if an explosion of this magnitude must be anticipated, say at a launch site, operations during any hazardous operation must be restricted or curtailed within a 9,000-foot radius; the danger will be less for smaller charges or systems of lower TNT equivalents.

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*No allowance has been made for the fact that damage is a function of energy release[4] and that the energy potentially available from standard composite propellants is greater than that from TNT.

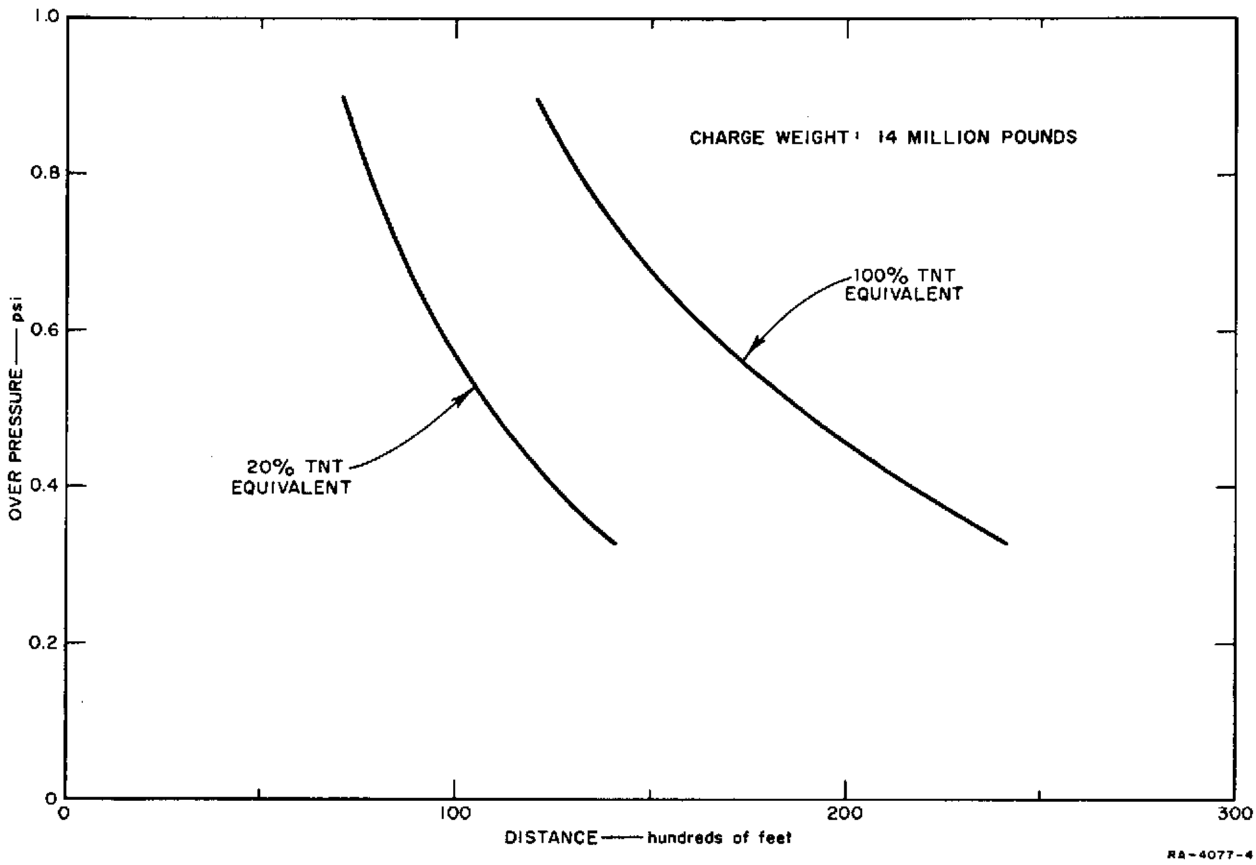

FIG. 1 BLAST EFFECTS OF PROPOSED NASA ASSEMBLIES

Even this superficial analogy must lead to the conclusion that the possibility, no matter how remote, of explosion of such a system cannot be ignored. No doubt, the nation's drawing boards have designs for even larger, more energetic systems.

To propose the necessary precautions, one must begin with an analysis of the situations in which these large systems are being used or might be used, the hazards which might be expected in these situations, and the possible results. Such a study will give responsible management an estimate of the risks associated with a particular action. The choice among several possible courses of action is a management decision which cannot be delegated. A brief study of the type outlined has been made by SRI's Propulsion Sciences Division. The study concerns only NASA space missions, and, to limit the area of the investigation, has been confined to studies of conventional composite propellants containing neither detonable binder nor other detonable ingredients. Nor have the possibility and consequences of enemy action been considered. It is appropriate to emphasize at this point that "safety" is <u>not</u> being considered. By "safety" is meant that area concerned with protective measures: how thick a wall should be, how many men can work safely or ought to be exposed under a hazardous set of circumstances, etc. Lastly, the problem of acoustic hazards has not been treated. For a consideration of this aspect, as it relates to the blast problem, reference can be made to the report of Ullian.[30]

It will be shown that, when being transported, segments of large motors present only a fire hazard. Completely assembled monolithic units, however, may explode. At all other times both types may be considered as Class II explosive systems except that, when fully armed or when the upper liquid stages are being fueled or are already fueled, they should be considered as Class X.[10]

II To What Hazards Can a System be Exposed?

The entire process through which a motor or stage passes in going from the manufacturer up to and including the immediate post-launch period can be conveniently, if arbitrarily, divided into five phases:

1. Shipment from the motor manufacturing plant to the receiving point.

2. Transportation at the receiving point.

3. Assembly, check out, and storage operations.

4. A period when the motors are on the launch stand and during which the normal pre-launch operations are being carried out.

5. A period immediately after launch, when the vehicle is still in close proximity to the launch pad and inhabited buildings.

Let us now direct our attention to each phase.

A. Shipment from the Motor Manufacturing Plant to the Receiving Point

As a first step the system must be lifted, probably by crane, onto some kind of transporter. This transporter may be directly suitable for use as a trailer for crosscountry travel or may, in turn, be loaded onto a railroad car, truckbed, barge, or airplane. Certainly even these may be specially designed for the task. For large monolithic systems it has been proposed that somewhat different techniques be used:[3] "In essence, the large weight of the motor would be borne for all transportation purposes by water. The motors would be cast in a floodable basin. For shipping, a caisson around the motor would be sealed, the basin flooded, and the container floated onto a special partially submersible barge. The barge is brought to normal attitude and towed to the launch facility."

With very little deliberation it becomes apparent that the following might occur.

a. A winch might fail and drop a stage or segment.

b. As a result of the above, or of inadequately designed equipment, the unit might hit the transporter or be squeezed or otherwise damaged as it is lowered into position.

c. During transportation, constant vibration and severe jolts, as from "bumping" of railroad cars, might cause damage.

d. At any time the unit might become the target, by design or accident, for small arms fire.

e. Train, highway, and other accidents are possible.

f. Temperature control devices might fail.

g. Proximity to other accidents and attendant risk is always a possibility: electric storms, nearby fire, or explosion, etc.

h. For seaborne or airborne systems the usual environmental hazards are present: storms, sinking of a barge, plane crash or explosion.

In similar fashion we arrive at considerations regarding possible mishaps for each of the remaining phases.

B. Transportation at the Receiving Point

With adequate planning, it is possible to design transportation equipment to minimize the number of operations involved when a small motor, stage, or segment is received at the launch site. For example, it should be possible to store each unit upon or within the transporter on which it is shipped. In general, traffic on a military or similar base is far more readily controlled than elsewhere. Accordingly, the probability of an accident is appreciably reduced.

For the large, monolithic motors,[3] the barge (after being brought to the launch facility) "is partially sunk, the caisson towed off, and maneuvered to the location of the launch pad. Water is removed from the launch basin and the motor caisson is maneuvered into the proper vertical position for launching the vehicle." Most, if not all, of the operations associated with this procedure are new and untried. It is therefore, patently impossible to predict many of the associated hazards; here, experience will be the best teacher. Nevertheless, for monolithic and for the more readily transported smaller or segmented units, most, if not all, of the situations itemized in the preceding section are applicable. In addition, since these units are now in the vicinity of other propulsive systems at the launch facility, the possibility of a malfunction of an adjacent motor (solid, liquid, detonable, etc.) with its associated dangers must be considered.

C. Assembly, Checkout, and Storage Operations

Once again any necessary movement exposes a motor to some or all of the hazards previously enumerated. In addition, certain conditions are peculiar to assembly, checkout, and storage operations.

Although monolithic units, by definition, eliminate the assembly manipulations, they have, as indicated above, their own problems. Segmented units must, of course, be assembled, as must the complete, but individual, units of a whole multi-motor stage. For this, special structures will undoubtedly be required. One type which has been suggested resembles the familiar pile of dishes seen in cafeterias. Here the pile is supported by a below-surface spring and, as each dish is added, the stack drops a small amount. With a similar arrangement it is foreseeable that each segment need be lifted only a small distance above ground level and carried until it is just above the segment to which it is to be fastened; then it may be lowered gently into place and assembly operations completed.

An alternative suggestion requires above-ground assembly within a superstructure of several decks. Each unit would be lifted into place and assembled.

An important problem here is that individual segments must now be carefully mated to each other at precisely machined and closely fitting interfaces. Unless these surfaces have been scrupulously cleaned and inspected it is possible that some propellant might be trapped and subjected to compression, shear, and other grinding forces.

This is also the first time during which large masses of propellant are brought into close proximity. This has a bearing on thermal stability and on detonation or explosion problems which will be discussed later.

Complete assembly requires the completion of a number of subassemblies. Among these are the destruct systems, and other devices which include explosive elements. This is the first time, since having left the manufacturer, that these explosive charges will be involved directly. A mishap here is always a possibility.

Except for the immediate pre- and post-launch periods, the phase during which the entire assembly is being checked presents the greatest real hazard. By this time, except for some last-minute insertions of ordnance items, the rocket is completely assembled. It may include as much as 30 to 40 pounds of high explosives, much of which is in the form of detonating cord or shaped charges whose sole purpose is to destroy the motor case. The nozzle is now attached, if this was not previously done. Premature ignition renders the unit propulsive. A very large number of the necessary "checkout" tests require passing significant electrical current through each of many components. Mistakes in wiring are not uncommon. Induced currents and other stray effects are present. These could conceivably actuate the ignition or explosive devices.

The checkout period is also a time for making repairs or modifications, or performing other operations upon the assembled system. Unless otherwise forbidden, these may involve the propellant, ignition, or ordnance systems and create safety problems.

Storage is, by definition, a period of quiescence during which no operations are being conducted, but it is not a time for relaxation. The hazards of large masses of propellants within each rocket are augmented now by their close proximity to other propulsion systems. Under normal circumstances, self-heating[6] occurs at a very slow, probably negligible, rate. As the temperature rises, so too does the rate of spontaneous decomposition. At high enough temperatures (probably over 200°F), explosion or violent decomposition results; at intermediate temperatures severe degradation is possible. This behavior is size-dependent: larger systems self-heat more rapidly. Consequently some temperature control such as air conditioning is probably required. The results of failure of the control system may not be detected until the actual launch phase.

Whether the moving of the completely assembled launch vehicle to the launch stand is to be considered part of the assembly or of the pre-launch period is unimportant for our purposes. Here again, whether monolithic or segmented, the techniques for moving such large systems (200 to 400 feet or more high) have not yet been developed. Certainly it is not inconceivable that such a large vehicle might topple, a gantry might derail, a nearby blast might knock it over, unanticipated instability might develop, overloaded structures might fail. For systems moved by barge similar considerations apply.

One possibility is that final assembly and checkout might be accomplished on the launch stand proper. Though this might sharply reduce the total number of operations involved in preparing a rocket for launch, it has major disadvantages: the launch platform is unavailable for other use for a much longer period of time, and the rocket being assembled is closer to other units and therefore more exposed to their possible malfunctions.

D. Pre-launch Period

Pre-launching is the period in which the completely assembled unit is on the launching platform, in position, and being made ready. It is the period during which the final checkout and countdown commence.

Significantly, it is also the period during which the liquid upper stages, if any, are filled with their energetic, often cryogenic, contents. It is neither our function nor our intent to delve into possible causes and the probability of malfunction of these units. We shall assume that "if it can happen, it will happen." The record shows, too, that 20% of attempted launches abort on or near the pad.[8] For a hydrogen-oxygen system, explosion or detonation is always possible. The consequences range from the resultant flying metal shrapnel and a high temperature fireball, up to and including a high pressure shock wave; any of these consequences may reach the solid first stage.

During this period, the rocket, if not the highest, is one of the higher objects in the immediate vicinity. It is a natural target for lightning. At some stage in the proceedings igniter squibs are installed, and explosive units may be armed (if they are not already). Nearby sources of electromagnetic radiation or other powerful signals may activate some types of these units prematurely. An error in routine electrical checkout, or a path through an unknown ground loop may do likewise.

This is also the last opportunity for repairs or modifications. As during the checkout period, these may involve hazardous operations on the propellant, ignition, or ordnance items.

E. Ignition and Immediate Post-Launch Period

During this ultimate operation a special condition exists. Until this moment everything humanly possible has been done to protect the rocket from any thermal or mechanical excursion. Now the grain is ignited, and the system accelerated. If the ignition system malfunctions, the interior of the grain may be subjected to too extreme a pressurization rate or to too high an ultimate pressure. The grain may crack or, worse, may shatter to expose more area to the combustion zone than that for which it was designed.[*] Assuming that the system performs correctly ballistically, the guidance may malfunction and once in the air, the now propulsive rocket may turn back towards the land, perhaps too soon for the safety officer to destroy the unit. Perhaps destruction can be accomplished and the rocket rendered nonpropulsive by fragmentation of the case and grain. The fragments of burning propellant will fall back to earth.

This completes the present list of the hazards to which a large solid propellant motor may be exposed. Most assuredly it is not complete, however, for the history of safety engineering demonstrates that not all possible causes of accidents can be anticipated.

III To What Hazards Have Systems Been Exposed?

It is useful to compare the abstract predictions with history -- what accidents have befallen rockets, and are there any not predicted?[**] Unfortunately, scientists and engineers, being human, brag about their successes. Failures don't seem to be reported regularly. Some, however, are on the record.

Are there examples of accidents which, though anticipated, have never occurred? Is the sample large enough -- experience broad enough -- to conclude that these will not occur?

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[*] Faulty inspection may permit an already cracked grain to reach this stage.

[**] The latter point is moot: the author knows the answer (or thinks he does) before he asks the question. However, any information a reader may have would be of immense help in completing the recorded history.

Experience with large solid motors is restricted largely to Polaris and Minuteman. One Polaris motor rolled off a truck. Another truck carrying a Polaris hit a snowbank. Both motors were x-rayed, found to be undamaged, and satisfactorily fired. The temperature control mechanism in one Polaris container failed during freezing weather; the motor was x-rayed and found to be undamaged. It has not been fired. The temperature control of another Polaris unit failed and the unit reached a temperature of 170°F for an indeterminate period less than one week. The propellant was a double-base composition, thermally more sensitive than those considered here; the mechanical properties were altered but no fire or ignition resulted. A railroad handcart bearing a Polaris ran past the stops at the end of the tracks, and the motor slid several inches. There is no record as to whether the engine was fired, but certainly there were no immediately serious consequences.[7]

The gantries on which complete assemblies are moved have never collapsed or been toppled. They have, however, been derailed.[10]

Despite many rumors to the contrary and the expectations of many, there do not appear to be any reported instances of bullet holes or marks on the units containing any rockets at the time of inspection at Cape Canaveral.[10]

Many years ago there seems to have been an accident in England, involving explosives, which bears upon the present problem. Either due to malfunction or to faulty procedures, the tires of a truck in motion rubbed against a container and overheated it. Explosion of the contents occurred.[9]

During one Polaris flight test at Cape Canaveral, the first stage malfunctioned and ignited the second stage which contained conventional propellant. The latter rose 300 feet, turned around and headed for the ground while burning at both ends. Though many fires were set and broken pieces of propellant continued to burn, there was no explosion.[7]

The "Abortive Missile Reports" are classified Secret and are, therefore, unsuitable for inclusion in this paper. A few significant facts can be drawn from them and, without violating security regulations, reported here.

(a) One solid propellant system impacted from an indeterminate height in the launch area. Though there were many fires, there was only a very mild overpressure and no significant damage.

(b) A large solid motor fell into the ocean after attaining an altitude of three miles. No propellant was aboard at time of impact, but - if it had fallen on land - there would have been many fragments from the case.

(c) The first stage of a two-stage solid propellant motor was deliberately ignited. A malfunction in the command system ignited the second stage which rose to an altitude of one-quarter mile, where it was destroyed with 3 tons of propellant aboard. Meanwhile, the first stage burned on the pad. Only fire damage was reported.

(d) Another solid propellant motor gave difficulty which caused it to impact with 3 tons of propellant aboard. The resultant explosion left a crater 8 ft deep x 15 ft across. No other damage was reported.

There are other reports involving solid systems. In general, though localized explosions are reported, there do not seem to have been any major blast effects. Rather easily controlled fires and some fragmentation of metal parts seem to be the rule.

Liquid systems, too, have malfunctioned. Mostly these are LOX/RP-1 engines. Many fires and some blast effects have been reported. In one instance peak overpresssures as high as about 1 psi have been reported at distances of 500 ft.

So it is apparent that many predictions have been verified. Missiles have been damaged in transit. They have been dropped, jarred, and shaken. They have been overheated and overcooled. They have ignited prematurely (but after command) and have impacted at the launch area.

They do not seem to have been the target of small arms fire, nor is there any evidence of their having been struck by lightning. There is no experience to indicate the premature activation of any ignition or explosive component except as the result of a faulty command. Squibs and detonators have, so far, behaved as intended.[8] There is no assurance that this record can be maintained. In fact, the experience of the industry is such that incidents of these types must be anticipated. There are 600 electric storms per year in the vicinity of Cape Canaveral.

IV Systematic Approach to Hazard Classification

On the basis of the preceding it has been established that:

1. Large solid propellant systems present a significant potential hazard.

2. Almost every type of conceivable accident has occurred. Of those which have not, it cannot be assured that they will not.

However desirable it may be, analysis of experience is not sufficient for hazard classification; a more systematic and complete approach is needed. It has been the policy of the explosives industry to anticipate and prepare for the worst possible disasters by simulating the conditions under which these might occur. Test results then act as a guide to the establishment of safety precautions. This is a conservative approach which suffers from one weakness: no account is taken of the probability of a particular type of accident. On the other hand there is a significant virtue in this approach: often tests under the worst possible conditions indicate the maximum hazard to be much less than anticipated.

Following this conservative philosophy a number of different types of tests have been run. These fall into the following categories.

impact and friction
sled
large-scale drop
bonfire
bullet

small-scale detonability (gap test)
large-scale detonability (Beauregard test)
thermal stability

Some of these, such as the bullet test, reproduce almost exactly a potential accident. Some, for example the sled tests, are attempts to simulate an accident. And some, e.g., the impact test, do not relate easily to any real situation. A brief discussion of each, with results, will be presented. An effort will be made to interpret the results in terms of their applicability to the situations discussed earlier.

A. Impact and Friction Tests

The procedure for tests of this sort is well known. The results which have been presented elsewhere[10, 11] can be interpreted to mean that conventional composite propellants are more sensitive to shock than are booster explosives. This simply is not so, and current thinking relates impact and friction testing to ignitability rather than to shock sensitivity.

Thus the lesson is that propellants seem to require less energy than explosives for ignition. Accordingly, missile handling techniques must provide maximum precautions against premature ignition. This applies particularly to the assembly of the units of a segmented system. Ignition could easily result from "tramp" propellant remaining at the joint. Depending upon the state of assembly this could make the rocket propulsive and, in any event, would certainly result in a very serious, probably uncontrollable, fire until all the propellant was consumed. Since, however, this would be a less severe ignition than normal, the system would not be expected to misbehave in any other way provided it could be restrained during the combustion period. Even if nonpropulsive it should not be permitted to fall, because this could make the grain crack and might lead to a pressure-type failure of the case and consequent spread of the burning propellant.

B. Bullet Sensitivity

Included in this type of test is any in which a high velocity metal fragment strikes a propellant sample or its container.

Results at Aerojet-General Corporation demonstrate that the propellants under consideration here are "relatively insensitive to bullet impact." A caliber .30 armor-piercing bullet having an impact velocity of about 800-1000 ft/sec at impact is required for ignition.[13]

Personnel at the Naval Ordnance Laboratory report[9, 14, 31] that bullets which penetrate the motor case may cause the motor to ignite but, with conventional propellants, nothing worse. The theory here is that the bullet creates a region of high temperature about its own path and only combustion results. A most interesting series of tests was run to establish the hazard classification of the relatively sensitive double-base 3rd stage of Minuteman. Caliber .50 armor-piercing bullets were fired into the motor from a distance of 100 ft and with a velocity of 2800 ft/sec. The motor ignited and developed full pressure and thrust 0.9 second after impact. Four seconds later the case ruptured. Even with this detonable system, only burning ensued.

C. Sled Tests

Solid propellant motors have been placed aboard rocket sleds aimed at striking concrete walls and with a velocity of 1000 ft/sec (680/mph). This generates a shock of the order of 14 kilobars.[14] These tests occasionally cause ignition; even with double-base detonable propellants detonations are unknown (one sensitive type of double-base explodes only when using a terminal velocity of approximately 3500 ft/sec = 2380 mph.)

D. Large-Scale Drop Tests

A standard test involves filling either a thin-walled motor or a standard bomb with the propellant in question and then dropping it from a height of 40 ft to generate a 1-kilobar shock in the propellant. Tests are run in which the drop is upon flat steel, a corrugated surface made from angle irons, or a surface from which large steel studs project for several inches. Polaris motors have been dropped on to flat steel plates. In general, ignition results if, and only if, the case is pierced by the drop.[33] Even with double-base propellants no explosions have resulted.[15]

E. Bonfire Tests

These tests originate from a desire to simulate what happens when a wooden boxcar containing explosives burns. In general, composite propellant motors subjected to this ordeal ignite, probably at the liner interface. The only consequence seems to be a mild pressure rupture with some flying pieces of burning propellant.[9, 14] This was the experience when a first-stage Minuteman motor was tested,[16, 17] and also with a third-stage Minuteman;[32] when the second-stage was similarly tested there was no case rupture.[17]

F. Small-Scale Detonability Tests

These tests have been well described,[12, 18] and of all sensitivity tests are believed to be on the firmest scientific footing. From these tests it has been quantitatively established that most double-base propellants, though detonable, are distinctly less sensitive than many of the least sensitive military explosives. It has been confirmed by these tests that the composites of the type considered here are nondetonable at and below diameters of the order of 2 inches (however, see below). On the other hand, it has also been established that the same composite propellants in a porous state become highly sensitive to shock and are detonated with an ease comparable to that of the energetic double-base formulations.

G. Large-Scale Detonability (Beauregard) Tests

There is as yet no adequate theory to predict the critical diameter of an explosive system. In an effort to determine the detonability of Polaris, using composite propellants, a series of tests, code named Beauregard, was performed during the summer and autumn of 1958 at the Naval Ordnance Test Station.[19] They established that the critical diameter for detonation of the solid nondefective composite propellant was above 20 inches. The implication of these tests is that motors of web thickness of the order of 20 inches or less are not detonable. On the other hand, considerable blast effect, attributable to the propellant, was recorded, which indicates that, in the presence of a severe shock, a significant quantity of the propellant reacted rapidly enough to contribute to the peak overpressure.

A detonation sensitivity test of a Minuteman second-stage engine was conducted.[20] The purpose was to determine if the engine would detonate when subjected to the detonation of a 100-lb shaped charge of composition B placed on the external surface of the chamber wall (not the head end). The explosion subsequent to initiation destroyed all recording equipment, which was located within a barricaded region approximately 250 feet from the charge.

Detonation sensitivity tests have been performed on full-scale Minuteman first and second stages,[17] using various test geometries. As with the Beauregard tests, though no detonation of the propellant was detected, significant blast effects were noted. It is not possible to scale these results to apply to larger systems.

H. Thermal Stability Tests

For a number of years a standard test, described elsewhere,[10, 21] has been used. It is often run by dropping a sample of propellant into a hot bath and determining the time to explosion. Of questionable theoretical value, it has the advantage of being, like the impact test, a simple one to perform and one which permits the ranking of various formulations according to their thermal sensitivity in a particular situation. Recently, more refined techniques have become available.[6, 22] These give considerable promise of being more generally applicable. The theory permits predictions, from the experimental results, of the temperature above which a sample of known size cannot be stored with safety. Although it has not yet been satisfactorily demonstrated that the results apply to large rocket motors, there are promising indications that this might be accomplished,[23] and improved methods are being developed to cope with geometries other than the simple ones to which the present treatment is restricted, i.e., cylinder, slab, or sphere.[24] We still need, however, a conclusive demonstration that the kinetic assumptions are valid and that the low-temperature energy of activation which these experiments determine is applicable to higher, predetonative temperatures. At any rate, the present information[6, 23] is sufficient to show that no safety hazard is presented by the storage of any conventional composite at any reasonable ambient temperature. This, notably, does not include degrading processes which may occur at extremes of temperature and which may be cause for rejection of a motor. On the other hand, high energy double-base materials are much more sensitive[6] to moderate temperature excursions. Multiple-stage rockets, of which one stage is such a sensitive material, should be protected from excessive heat. There are, so far, insufficient data to permit the establishment of general criteria for storage of energetic propellants.

V Significance of Testing - Hazard Classification

How do these tests relate to the actual hazards of missile handling? Consideration of the many types of mishaps which have occured or which reasonably might happen leads to the conclusion that to each type of mishap, regardless of the operation during which it might occur, one or more tests of the types already described correspond. The proper hazard classification depends upon the proper interpretation of the existing tests. (For some situations, additional testing might be desired.) Table I analyzes the previous discussion by correlating hazards with the operation phase during which they might occur and with the pertinent sensitivity test.

It is apparent that the approximately forty (somewhat arbitrary) different combinations of malfunctions can be evaluated, with few exceptions, by one or more of seven types of test.

[redacted]

18

Table I

HAZARD	SITUATION OR PHASE OF OPERATION					PERTINENT TEST							MISCL.
	Shipment	Trans-portation on Site	Assembly Checkout Storage	At-Launch	Post Launch	Impact	Bullet	Rocket Sled	Large-Scale Drop	Gap	Beauregard	Thermal Stability	
Winch failure	x	x		x				x	x				
Improper loading on transporter	x	x						x	x				
Jolting-"bumping" vibration	x	x		x				x	x				Vibration
Small arms fire							x						
Train, hiway, other accidents	x	x						x	x			x	
Failure of thermostat	x	x	x									x	
Proximity of other accidents	x	x	x	x			x	x	x	x	x	x	
Seaborne or airborne accidents	x	x						x	x			x	
Tramp propellant caught at joint			x			x							
Large masses brought together			x	x	x						x	x	
Ordnance malfunction			x	x	x			x	x	x		x	Subassembly testing
Premature ignition			x	x	x			x	x	x		x	Subassembly testing
Modification of mtr.			x	x				*					
A large mtr. topples			x	x				x	x				
Explosion of liquid stages				x	x		x					x	Effect upon ord. items
Lightning & electro-magnetic radiation				x								x	Effect upon ord. items
Ignition malfunction					x					x			
Guidance malfunction					x			x	x				
Burning of defective grain					x					x	x		
Activation of destruction system					x					x	x		

* Depends upon modification

[redacted]

With one exception, all of the anticipated situations which may occur during shipment or on-site transportation are comparable to bullet, rocket-sled, large-scale drop, or thermal-stability tests. The exception involves the relation between the "proximity to other accidents" and the shock-sensitivity type of test (gap or Beauregard). Later it will be shown that no explosion originating from beyond the rocket (meaning the entire assembly of several stages) can generate a shock strong enough to do anything but fracture and perhaps ignite the grain. The results of all other tests indicate that the worst possible consequence of an accident during transportation would be a severe fire. Individual segments open on both ends would merely burn. A monolithic rocket could rupture (pressure-vessel-type failure) or become propulsive. Insofar as existing shock sensitivity tests indicate, neither system, monolithic or segmented, is detonable.

During assembly, checkout, and storage, all of the tests are relevant. Again except for the shock sensitivity tests, all existing data and test results indicate that no reasonably conceivable accident could cause any but a fire hazard. If the segments have been assembled or if the system is of the monolithic type, a propulsive condition or a pressure vessel failure may result. It is now the practice at Cape Canaveral to use large physical barriers to prevent a propulsive system from "launching" itself.[8] If this procedure is adopted for larger systems, such as those envisioned for NASA missions, they may be classified as Class II. The results of the shock sensitivity tests indicate that, even if the propellant is nondetonable, the propellants are capable of contributing to the shock from a nearby detonation. The extent of this contribution cannot be forecast at the present time. If conventional propellants are to be used in conjunction with double-base or other detonable formulations, it might seem that the entire system should be so classified. This is an overly conservative approach; however, more work is needed to develop the necessary scaling laws. The likelihood of this combination being used appears, at present, to be slim; accordingly, it is best to delay consideration of the problem until it is germane.

There may be concern because of the presence of a quantity of explosive units or systems aboard the rocket. Most of these are in the form of explosive bolts or actuators or conventional linear or shaped charges for destruct systems. These are designed for a specific function which normally involves, locally, a relatively small explosive effect (the total amount of explosive present is not the criterion). At worst they will rupture or perforate the motor case to make it nonpropulsive. They may also shatter a small quantity of, and ignite, the propellant. The result again is fire; neither propulsion nor detonation is a likely consequence. A pressure rupture is a possibility.

Current regulations at the Pacific Missile Range[26] permit neither redesign nor modification of any element of ordnance, including the propellant system. Such work must be done by the manufacturer at a facility, other than PMR, of his choice. The decision as to when removal of the unit is required is made by the Range Safety Officer, not by the manufacturer or his representative. At Cape Canaveral similar restrictions apply.[8] Mechanical repairs can be made. For repairs of a nature which expose the propellant, the system is moved to a specially secured area. For significant grain or ordnance repairs, the unit is returned to the manufacturer. The decision is made by the Range Safety Officer. So long as this policy is rigorously pursued, no significant additional risk is seen. The manufacturer should be divorced from the decision; range safety personnel, if they err, will err on the side of caution.

The problem of "tramp" propellant at the surface where segment juncture is to be accomplished has been considered in the section dealing with impact testing.

In summary, during the assembly, checkout, and storage periods, provided that a propulsive system can be <u>restrained</u>, conventional systems should be stored as Class II explosives, presenting fire and some pressure vessel (with fragmentation) hazards.

During the pre-launch period much of the foregoing applies. A review of the discussion on possible hazards during this period indicates the existence of several paths for activation of ordnance units. For this reason it has been the practice to install squibs, igniters, and detonators as late in the countdown as possible, perhaps as little as 75 minutes before launch. Subsequent to this time stray E. M. F.'s may activate destruct or ignition systems (or both) or perhaps separate stages prematurely. Destruct system activation renders the system nonpropulsive but starts fires and may climax with pressure type burst. Ignition renders the unit propulsive and stage separation may, in the extreme of a filled liquid oxygen-fuel system, cause a serious explosion. More will be said about this last possibility. Premature ignition with resultant propulsion can be handled promptly by deliberate destruction. Hence, except for the possibility of nearby explosion, the system can again be treated as a Class II fire hazard with some possibility of fragments; for the post-launch period, explosion on the pad is possible. For a propulsive rocket returning too soon, with a liquid stage aboard, to strike at or near the launch site, motor rupture is probable. (The impacting of a burning grain is not the same as the superficially comparable rocket or drop tests on unignited burns.) In either case there is insufficient information upon which to base a hazard classification. Certainly the rocket presents a real explosion hazard and cannot be considered Class II; on the other hand, if it is nondetonable, neither is it Class IX or X.

Except for a deliberate vagueness concerning the detonability, it has been indicated by the foregoing that the large conventional solid propellant motors destined for NASA missions offer only fire, pressure rupture, and associated fragment hazards.

Detonability is dealt with at length in the next section. However, to complete the list of recommendations for proper hazard classification, the conclusions will be presented here. Until the igniter, completely assembled, is installed, or until the upper stages are being filled with the liquid fuel and oxidizer, the solid grain can be considered as Class II. However, once either or both of these steps have been taken, the entire system must, under existing regulations, be considered as Class X, and a new, larger security area defined around the launch pad unless a waiver is granted. This conclusion is independent of whether the propellant is, itself, capable of sustaining a stable detonation and imposes a severe handicap upon the facility. Current regulations do not provide for the condition in which a solid motor presents an explosive hazard significantly less than that to be expected from the detonation of an equivalent mass of high explosive. Under such circumstances the service or agency concerned may grant waivers based upon a realistic estimate of the hazard; modified handling and storage conditions are then authorized.

VI Detonability of Conventional Solid Propellants - Is It Important?

It is now necessary to evaluate the importance of the detonability of the propellant under consideration. The term "detonation" is used in its completely rigorous meaning: a chemically supported shock wave, of stable velocity, propagating with a velocity which is supersonic with respect to the unreacted medium. This is in contrast to an explosion, which merely implies a violent reaction.

Small-scale gap tests confirm merely that conventional composites will not detonate in diameters of the order of 2 inches. The Beauregard tests confirm that the critical diameter is greater than 20 inches. Boyer[27] at Aeronutronic has made a preliminary prediction that these materials will not detonate at any diameter. On the other hand, Anderson[28] at Aerojet feels that the critical diameter is of the order of 40 to 60 inches. To test these theories it would be necessary to prepare several, probably four, propellant samples each of the diameter to be tested and of length at least six times the diameter. (The Beauregard tests show that for diameters greater than 20 inches a length to diameter ratio of 4 is inadequate.) Assume that the diameter to be tested is 60 inches; this is very close to the web thickness of a 120-inch motor, mentioned earlier. The length would have to be 360 inches, the volume would be 655 cu ft, and the propellant would weigh approximately 65, 500 lb. At $1. 50 per pound, four such samples would cost about

$400, 000. The explosive boosters might cost half as much. Thus, over $600, 000 would be required merely to buy the test components. Over and above this are the costs of hardware, transportation, instrumentation, and designing the test, and arranging for the necessary personnel to supervise the operation and analyze the results. Obviously this would be a multimillion-dollar undertaking.

Assume that the tests are run and show that the propellant is detonable in 60 inches diameter. There is still no indication as to how great a shock is required for initiation. The additional testing required to obtain this information could easily treble or quadruple the cost. If the additional testing is foregone, the conservative assumption can be made that the propellant is about as sensitive as some of the composite propellants with high energy binders. These latter require shock pressures of the order of 60 kilobars for initiation.[12] Explosive sensitivity research teaches that in order to detonate an explosive the requisite shock pressure must be applied to the acceptor (in this case the propellant) over an area approximately equal to $(\pi\frac{d}{2})^2$, where d is the critical diameter. Thus, even if the propellant is detonable, its detonation requires an approximately 60-kilobar shock wave over a plane circular surface having a 60-inch diameter. For larger critical diameters the problem is proportionately larger, of course. Only a nearby detonating explosive of 60-inch diameter or greater could generate such a shock. The only reasonable source is the liquid stage above the solid. Estimates have been made of the shock pressure in a liquid hydrogen-liquid oxygen detonation; it is reported[29] that this may as high as 45-50 kilobars and, correcting for impedance mismatching, perhaps double that in the propellant acceptor. For the gases it will be lower. Even worse, the LOX/RP-1 system may generate pressures[23] as high as 140-150 kilobars. Allowing for a reasonable interstage separation distance plus the intervening hardware to attenuate the shock, it may be unlikely that an initiating shock will reach the solid propellant. Although the possibility of a transition from burning to detonation of the solid must be considered, it has been demonstrated, even for the sensitive double-base systems, that pressure rupture of the motor cases occurs rapidly enough to preclude such an incident. Thus, the one mechanism by which a shock-initiated detonation becomes possible requires a precursor detonation of the liquid second stage.

On the other hand, the history of gap testing demonstrates that cracked or granular systems either detonate (stably) or contribute a large amount of energy to the explosive shock wave. Even if the propellant is nondetonable, the occurrence of the postulated second-stage detonations could initiate a fracture process which would furnish the medium for the explosive reaction. Our ability to predict the extent of fracture and the magnitude of the explosion is inadequate. Much depends upon the source and location of the fracturing pulse. If it is external to the grain and at the head end, damage might not exceed that resulting from a 20% TNT equivalent for the first stage.[17] Undoubtedly the nature of the motor would have a strong influence. A crack might propagate easily through a monolithic grain. It is hard to see how it would propagate beyond the first segment of a multi-segment motor. An internally generated (as from ignition) shock might be sufficiently severe to shatter a large percentage of the propellant -- segmented or otherwise. If the source was on the external wall midway between the ends, as with the Minuteman test,[20] a great contribution might also result. Unfortunately, there is no known way to simulate these tests on a small scale -- not enough is known about fracture mechanics. Adequate testing would have to be of a statistical nature, and full-scale motors with complete upper stages would be required. The cost would exceed, probably by one or more orders of magnitude, the high cost of the relatively simple detonability test. For example, the full-scale tests proposed for Minuteman in-silo hazard classification would have cost $16,000,000 or more.[38]

The possible blast effect caused by an explosion of a specific solid propellant motor is determined largely by the donor shock. Though the propellant acceptor may be above its critical diameter, the donor shock may be insufficient to initiate detonation, while at the same time causing a violent explosion (subsequent to grain fracture). Consequently, whether the solid grain exceeds its critical diameter is of less importance, as far as hazard evaluation is concerned, than the integrated effect of the explosion of a liquid or other detonable donor and solid propellant acceptor in the configuration of the actual rocket.

VII Discussion

We are now on the horns of a dilemma. On the one hand is the option of classifying all solid propellant systems as Class X explosives, regardless of the formulation. Such a course immediately determines the necessary quantity-distance criteria for the design of acceptable facilities. Further testing is obviated. Among other advantages are the fact that such a conservative approach permits a later change to a detonable propellant with no penalty. Disadvantages include the restrictions imposed upon site operations.

Recognizing, however, that the traditional classifications (II, X, or what have you?) cannot realistically represent the actual danger, one alternative is to test the full-scale system under the worst credible operating conditions. Advantages include the great likelihood that less severe restrictions need be imposed than those dictated by Class X requirements. Concomitant are the decreased program expenses, delays to this and other programs, reduced real estate requirements, etc. Disadvantages include the great expense, in time and money, of minimum tests, the not inconsiderable problem of defining and designing minimum tests, and the fact that no provision is made, in system siting, for the potential later use of detonable systems.

In short, though Class X requirements are too severe, the alternative also has serious disadvantages. It cannot be recommended too strongly that the decision as to which course should be taken inevitably involves many millions of dollars, and should be made with a view towards the nation's entire space and missile effort; a piecemeal approach, considering only the cost to a particular system, cannot be adequate. (See, too(38).)

Meanwhile the wisdom and feasibility of accepting either course, at least as this concerns future systems, can be affected in part by the results of certain relatively inexpensive supporting research such as that suggested in Part III of this report.

VIII Summary

Evidence has been accumulated and is presented in such a way as to justify the following hazard classification for the large (conventional) solid propellant motors envisioned for NASA space missions.

While being transported, motor segments may be considered as fire hazards only; monolithic systems, in addition, may become propulsive or may rupture. During storage, checkout and assembly, both types may be handled as nondetonable, Class II systems. They may also be Class II on the launch pad, prior to arming of the igniter or fueling of the liquid stages. From that time on, they must be considered as Class X detonable systems. Alternatively, a series of expensive full-scale hazard tests may permit reduction of the hazard classification.

IX Acknowledgments

To gather the required information we have conducted a critical survey of pertinent literature, including journal articles and project reports, both classified and unclassified. Of considerable help, too, have been our conversations with a number of authorities who have been very helpful. Although the author takes full responsibility for the contents of this section of the report, we should like to thank the following people for their help.

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PART TWO: PROPOSED "EXPLOSIVES HAZARD CLASSIFICATION PROCEDURE" ANALYSIS AND CRITICISM

I Introduction

The Armed Services Explosives Safety Board (ASESB) has, for some time, been in the process of revising its "Explosives Hazard Classification Procedure." The final document, when accepted by the Services, will establish uniform criteria for tests from which hazard classifications and hazard characteristics of explosive items and explosive assemblies used by the Department of Defense agencies may be determined, and to establish a procedure that will cause the same hazard classification to be assigned by all such agencies to any one explosive item or explosive assembly which is handled under similar circumstances.

This represents a significant step towards the solution of problems arising with the advent of systems incorporating large masses of energetic materials of questionable detonability. The ASESB has accomplished a major task in the face of great difficulty and in an area in which little solid technical knowledge is available for guidance.

The previous section of this Final Report dealt with the broad problem of considering all of the hazards to which conventional solid propellant motors might be exposed and estimating their consequences. In this section the applicability of the proposed ASESB procedure to these same systems is explored. It should be absolutely clear to the reader that what follows applies only to conventional solid propellants with nondetonable ingredients.

Section III of the referenced ASESB proposed classification procedure is entitled "Introduction to Minimum Test Criteria for Solid Propellants and Rocket Motors or Devices Containing Solid Propellants." This is the section which this report treats in detail and it is suggested that, at this point, the reader familarize himself with its contents*. Upon doing so he will note that the proposed tests are considered as applying to one (or more) of four phases. Each of the latter is designed to establish, at an appropriate stage of propellant development, the precautions to be exercised.

II Detailed Analysis and Critique

Phase I relates to problems encountered in the utilization of "a few pounds of propellant" and is designed to ascertain whether quantities of one-half pound or larger can be shipped by commercial transportation. The required tests include detonability, ignition, thermal stability, impact sensitivity, and differential thermal analysis, and classification is assigned according to a formula utilizing information as to which of the tests produced a detonation. Of the tests enumerated, only the detonation test is suitably instrumented to determine, even qualitatively, whether the sample has detonated. The sample may explode during the other tests, but the difference between an explosion and a detonation is precise and significant, and sophisticated techniques are required to detect a true detonation. For the case under consideration it would be particularly unfortunate if a propellant were to be labelled falsely as being detonable. Thus, although the tests specified definitely do help to determine the limits within which a small sample can be shipped safely, exception must be taken to the conclusion that detonability can be detected by any but detonability tests.

Phase II tests are designed to permit classification of quantities "from a few pounds of propellant to full scale motor." Critical diameter, card gap, external heat, and bullet impact tests are specified. Again the critical diameter and card gap tests relate

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*For convenience, Section III of the ASESB tentative procedure is reproduced as an Appendix to this report. If and when finally approved, it will appear as a change in Department of the Army Technical Bulletin TB 700-2, Department of the Navy NAVWEPS Instruction 8020.8, and Department of the Air Force Technical Order 11A-1-47.

directly to detonability and can be interpreted simply. However, the specified test conditions require that eight-inch-diameter samples be used and that measurements be made of the contribution of the propellant to peak blast pressures. For a given shock donor and with truly nondetonable acceptors it has been established that the measured TNT equivalent decreases with increasing length of the propellant sample. Thus, though this test does relate to establishment of shipping criteria for these small samples, the TNT equivalents calculated from peak pressure measurements cannot be extrapolated to larger systems, especially those of complex geometry.

The "external heat" test exposes the entire underside of a 5-inch-diameter simulated "work horse" motor directly to the flames of a lumber or fuel oil fire for 30 minutes or more. "Detonation, explosion, or pressure failure" are reported, along with a fragment-despersion pattern, if any. Again, exception must be taken to the test's implied ability to detect a detonation. Also, the results are peculiarly a property of the motor as well as of the propellant, and extrapolation of any of the results to other situations or to other and larger motors would not be valid.

The requirements and interpretation of bullet sensitivity tests are subject to the same limitations.

Final classification samples of Phase II size depends upon interpretation of these test results. However, if Phase I testing categorizes the propellant as ICC class A[25] or Military Class 9, it must be so classified for Phase II purposes regardless of the outcome of the Phase II tests. Here is an excellent example of the dangers of misinterpreting tests and extrapolating their implications. Thus, under Phase I, if the ignition test is reported as producing a detonation, it would seem that the propellant must be classified as mass-detonating even for Phase II purposes.

The Phase III tests are designed to determine the actual hazard characteristics of full-scale rocket motors or devices selected for end item usage, the associated hazard classification, and the required quantity-distance relation that is required for safety. Quoting the tentative procedure, "this phase will demonstrate the actual hazards associated with a rocket motor or device when exposed to detonation, fragment penetration, fire, and drop. Further, only upon the completion of this phase of testing, and when the results indicate essentially only a fire hazard, can the Interstate Commerce Commission classification be changed from A to B and Military classification be changed from 10 to 2." Presumably, although it is not stated explicitly, individual segments would be classified separately when used separately rather than according to their behavior when assembled. Furthermore, it is to be hoped that the classification might be permitted to vary with the element of risk inherent in a particular situation.

The Phase III tests include drop, external heat, bullet impact, and detonation tests. If any of these tests results in a detonation, it is required that the system be classified as mass-detonating, yet none of the prescribed tests (including that for detonability) is suitably instrumented for this purpose.

The tests are to serve as a guide for establishing quantity-distance requirements; these, of course, are independent of the determination of detonability but should relate to the hazard to which the system might be exposed. We recognize the realism of the drop and bullet impact tests, although, in view of the vast amount of information already available, the necessity of performing them repeatedly on the same types of propellants is open to serious doubts. The expense of performing these tests is so great that elimination of those unnecessary and redundant should be greatly encouraged.

The external heat test presumably evaluates the response of the test unit to a severe fire and, reportedly, reproduces the situation in which an explosive unit is in a burning boxcar. For the units under consideration here, highly specialized transportation (and storage) facilities and procedures are being considered and designed. Presumably, all such required equipment will be fireproof. Although the possibility of fire cannot be ruled out, the severity of the test fire seems, on the one hand, to impose too great a penalty upon the system, and, on the other, to ignore other, equally or more probable, thermal excursions. Serious attention should be given to evaluating further the applicability of more scientific tests such as adiabalic self-heating or differential thermal analysis. In principle, the results of these tests can, with suitable mathematical support, be applied to various geometries and temperature environments and are, therefore, capable of more general utility. Lastly, as relates to the quantity-distance problem, individual segments will not explode. It is a needless extravagance to subject them to bonfire tests.

The detonability test, like the bonfire test above, does not seem to relate to any real possible situation. The test is not instrumented to detect a detonation. Furthermore, the small size of the required pentolite booster (2 inch diam. x 2 inch length) is inadequate to initiate detonation in any but those propellants whose critical diameter is of the order of two inches or less. It will already have been established by previous (Phases I and II) testing whether this condition exists. For the conventional propellants of very large critical diameter, this test will not initiate a sustaining detonation, although it may induce a relatively mild explosion within a restricted region of the test propellant. The test is aimed at reproducing a given hazard; it is difficult to see what this hazard might be. Though it simulates the situation involving a violent igniter-induced pressure excursion, there is far too little information on either such excursions or the proposed test conditions to indicate whether the equation is valid. Even if it is, such excursions can occur only after the igniter is installed and armed, i.e., while the fully assembled motor is on the pad. The motor or its segments should not be penalized at all times for the potentially extreme hazard existing only during a short, well defined interval.

Phase IV tests are to apply to full-scale missiles and are designed to simulate use conditions. Unlike the preceding tests they are not mandatory except at the instance of the agency or service involved. Of the several tests suggested, two appear to be germane to the conditions treated here, viz., those aimed at measuring the effects of destruct systems on motors and of the detonation effect of one stage of a missile on the remaining stages of the same missile. The latter, being a far more severe test than the former, is also the more important. No test suitable to this objective is described in the tentative procedure, however.

III Summary

As detailed in Part I of this final report, there is more than ample evidence to confirm that the conventional propellants are nondetonable except in very large diameters, as yet undetermined. The tests required by the proposed "Explosives Hazard Classification Procedure" appear to be directed toward relatively detonable systems of small critical diameter. It appears that application of the test series to conventional composite propellants cannot be recommended, since the results may be misinterpreted in such a way as to penalize the system unduly by requiring too conservative a classification. It is apparent that a special set of tests must be designed to satisfy the unique requirements of large conventional composite propellant systems.

PART THREE: RECOMMENDED ACTION

The really hazardous stage in the use of large solid motors, especially those of the segmented variety, arises only when the unit is on the pad in preparation for launching. In particular, two potentially dangerous events can occur. If the igniter malfunctions or if the second stage explodes, an explosion of the first stage might ensue. The latter would most probably be the more serious event and should, therefore, guide the establishment of safety precautions. Unfortunately, the ASESB-recommended hazard classification procedures furnish no guidance in this area. It remains therefore for a specially devised approach to be taken. This is the subject of this section of the report, and is discussed along two lines. First, consideration is given to the design of tests for immediate solution of the problem of establishing a hazard classification for the motors. Then, suggestions are made for supporting research to be initiated and aimed at the more general problem of solid propellant hazards.

A. Full-Scale Hazard Classification Tests

There is insufficient basic knowledge to predict the behavior of the systems under consideration; furthermore, there is no way of designing a sub-scale test whose results could be reliably extrapolated to the full-scale situation. The alternative to accepting the Class X classification of the rocket on the stand is to perform a full-scale test designed to simulate as closely as possible the worst accident which might realistically be anticipated.

Unless the tests are run, the quantity-distance relations for a Class X system must apply, assuming a 100% TNT equivalent for the propellant. Experience with other systems, such as Polaris and Minuteman, indicates that the 100% figure is very probably highly conservative, and that a more realistic allowance is probably in the range of a 30-60% or even lower TNT equivalent. Nevertheless, since there are no reliable scaling laws, these latter figures cannot be accepted without further testing; therefore, during terminal stages of the launching operations, areas within a very large radius of the launch pad must be secured against possible explosion. This action is expensive in that numbers of people are idled, buildings within the radius must be made explosion-proof, and other programs must be delayed. Finally, to prevent the exposure of civilian off-base personnel and facilities, additional real estate may have to be bought.

The alternative is also very expensive. The tests must be full-scale (see, however, par. 4 below) and each motor tested will cost many millions of dollars. In addition, there are the costs of auxiliary instrumentation, transportation of the motor and other equipment to the test site, and the entire cost of planning, managing, conducting, and evaluating the tests. This cost is very dependent upon motor size but certainly would be of the order of five to ten million dollars per test. Then consider that, for some measure of reliability, the test should be duplicated, and that every time a significantly new propellant formulation or motor design is proposed further tests must be considered. Obviously this, too, is a costly procedure, is time-consuming, and requires motors probably needed urgently elsewhere.

The decision as to which course to follow is difficult. If the tests are required, it appears that they should be of the following general design.

Let us assume that the system considered does have a H_2-O_2 second stage.* Schematically, the rocket may be represented as in Figure 2A.

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*The conclusions drawn herein apply generally to any other liquid system.

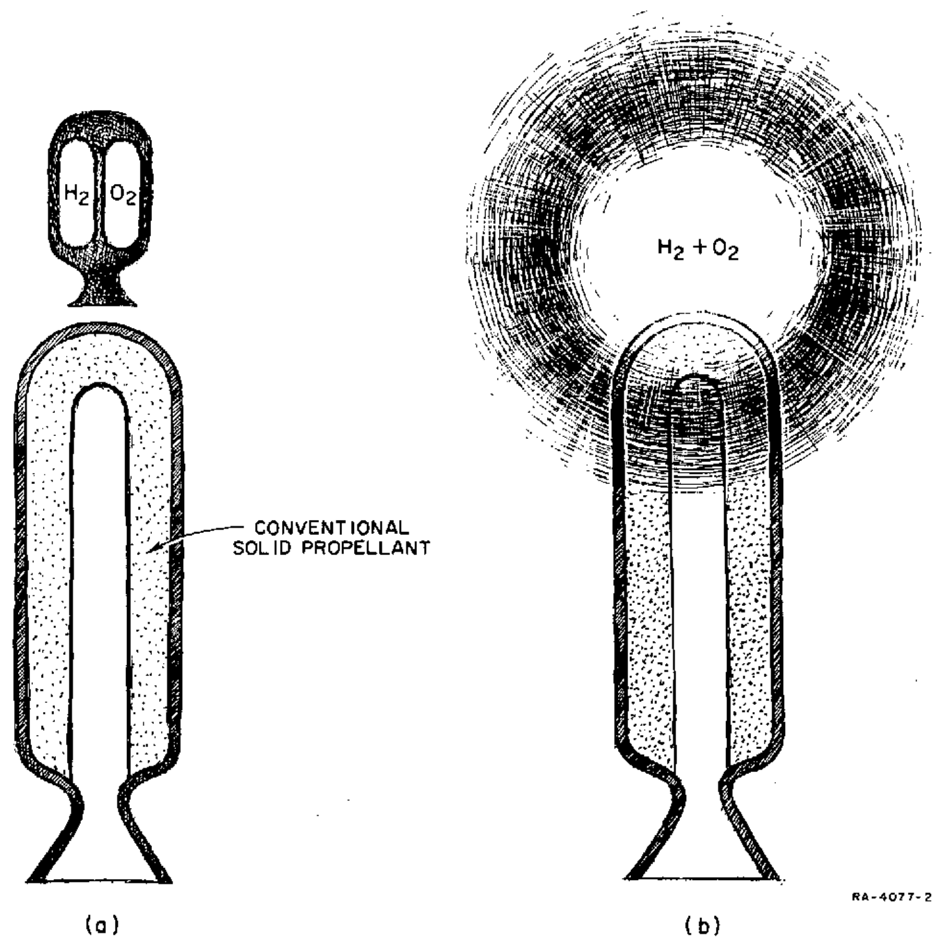

FIG. 2 EXPLOSION OF SECOND STAGE ENGINE

The worst possible accident would involve a detonation of the hydrogen and oxygen after they became completely mixed. Suppose the tanks, both of hydrogen and of oxygen, were to leak or rupture simultaneously. Assume that the liquids, as they evaporated, became completely mixed. Furthermore, assume that the final volume was that of the mixture, totally vaporized, but still at the boiling point of oxygen, 90°K. Further, let this be an approximately spherical volume centered at the original center of gravity of the intact second stage. If, as is likely, this volume was large enough to include a part of the first stage and inter-stage hardware, an allowance would have to be made to increase the radius of the sphere to compensate for the volume within the sphere not available to the gas mixture. We now have the situation shown in

Figure 2b. The test would require duplication of this situation, followed by initiation to detonation of the gases. Sufficient instrumentation should be provided to permit measurement of

a) shock velocity within the gas volume and within the propellant
b) peak air blast pressures along several radii and at several distances from the explosion
c) seismic, noise, and fragment effects of the explosion.

Some exploratory development is obviously required to assure that the hydrogen-oxygen explosive donor can be assembled properly, safely, and reliably.

Accordingly, if the decision is made to conduct these tests in the very real anticipation that, by so doing, safety requirements can be relaxed, the following should be undertaken, immediately, in the order given.

1. Development of procedures for safe mixing of large quantities of H_2 and O_2 in the same proportions as are used in liquid engines. This should include an investigation of the probable final temperature and state of the system resulting from the spontaneous, irreversible mixing of the two present initially as liquids at their respective boiling points.*

2. Detonation, preferably in duplicate, of the resultant mixture. Satisfactory design and scaling of these tests requires that the size of the liquid stage or stages of the rocket be firmly established previously. The center of the charge should be at a distance above the ground which is the same as the distance from the center of gravity of the rocket second stage to the ground. These should be instrumented as previously described.

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* Reportedly, preliminary studies of this type have been initiated by Professor Melvin Cook of the University of Utah.

3. Using the above information, initiation of a brief study to determine whether the explosive effects of the liquid stage can be duplicated by a much simpler-to-assemble solid explosive unit. Design of such an explosive donor, if possible.

4. Repetition of step 2, in duplicate, using either the explosive donor of step 3, or the H_2-O_2 donor of step 2 in association with the rocket first stage. For this set of tests it is necessary to consider the extent to which all of the hardware of the first and second stages must be duplicated. Much of this is very expensive and should not be needlessly destroyed. On the other hand, the interposition between the shock donor and the solid propellant of a certain amount of inert attenuation is necessary to duplicate the actual conditions. Similarly, it probably is not necessary to include much of the hardware at the exhaust end of the solid motor except insofar as fragmentation hazards are to be studied. In any event, the tests must be designed to simulate the effect of an explosion of the liquid stage in situ above the solid first stage. It may be possible to conduct these tests on less than full-scale. For example, if the solid stage consists of a cluster of individual motors arranged in a circle about or below the liquid stage it may be sufficient to use only one of the cluster, while still retaining the spatial relation. This possibility should be investigated promptly with the use of small scale assemblies.

B; <u>Suggestions for Supporting Research</u>

It is appropriate to itemize some of the important problems for which, at the present time, there are no answers. These are those towards which study should be directed.

1. When subjected to severe hydrodynamic shock, how much of a given propellant will fracture? How does this depend

upon: the pressure in the leading edge of the shock, the time behavior in back of the leading edge, the mechanical properties of the propellant? Under what conditions will pure shock initiate burning in the fractured propellant? How fast will this burning propagate? Will additional propellant fracture and burn as a result? To what extent will the rapid deflagration contribute to the over-all shock pressure? How does propellant geometry determine the results?

2. What is the critical diameter (for detonation) of typical propellants? How is this affected by geometry (e.g., grain perforations), by mechanical properties, by formulation? Can present theories predict critical diameter? If so, what data are required and, of these, which are unavailable (e.g., reaction rates and equation of state data at high pressures and temperatures)?

3. The blast effect contributed by an exploding motor (of conventional solid propellant) is determined by, among other things, the strength of the initiating shock. The nature of this problem has been discussed in the previous section dealing with the requirements for full-scale test with H_2-O_2 donors. If the H_2-O_2 system can be made hypergolic, as with O_3F_2, to what extent does this reduce the shock strength? For that matter, can the hypergolic system be made to detonate?

4. Many very crude tests exist for measuring the thermal stability of propellants. To what extent can these be replaced by the more sophisticated techniques of adiabatic self-heating or differential thermal analysis? Can the maximum safe storage temperatures for various system sizes be related to the results of such studies? In fact, can these chemical kinetic studies be used, in lieu of high pressure and temperature data, in studies of detonation parameters?

Let us consider each of these problem areas in the order given. In the field of fracture mechanics very little work has been done. Most of the studies of the viscoelastic response of propellants have been aimed at the long-term storage problem, definition of residual stresses within a cast and cured grain and at behavior during normal ignition. Very little is known about the mechanical response of composite propellants to hydrodynamic shock. It is not possible now to define the shock limits beyond which fracture will occur, or, when it does, such things as propagation rate or direction and number of failure sites.

A series of experiments designed to study this problem should be initiated. For example, long cylinders of inert propellant should be subjected at one end to shock. As is shown in Figure 3, this will cause fracture within a certain sample length. This length and the size distribution of the resulting fragments should be measured. The dependence of the results upon the initial shock profile and the shock and sample dimensions should be studied. Then the effect of changing sample geometry should be examined. For example, the extent to which grain perforation affects the fracture propagation pattern should be determined. The idea behind these studies is that the contribution to a shock wave of an exploding propellant originates largely from the explosively rapid combustion of that portion fractured by the initiating shock. Of course this combustion may in turn generate shocks which will fracture more propellant; however, analysis of the complete process into its component steps is prerequisite to understanding the over-all process.

These studies will have to be conducted on a true propellant simulant, for early work by Jones at DuPont demonstrated the vital role played by the binder-oxidizer surface in rapid fracture[34].

Subsequent to these tests (or as a part thereof), it would be important to watch the initiation and propagation of combustion within the fractured propellant. Not only should such combustion be initiated by shock but also by heat, as in the experiments of Macek,[35] using already fractured samples. Sophisticated electronic and very high speed photographic techniques would be required.

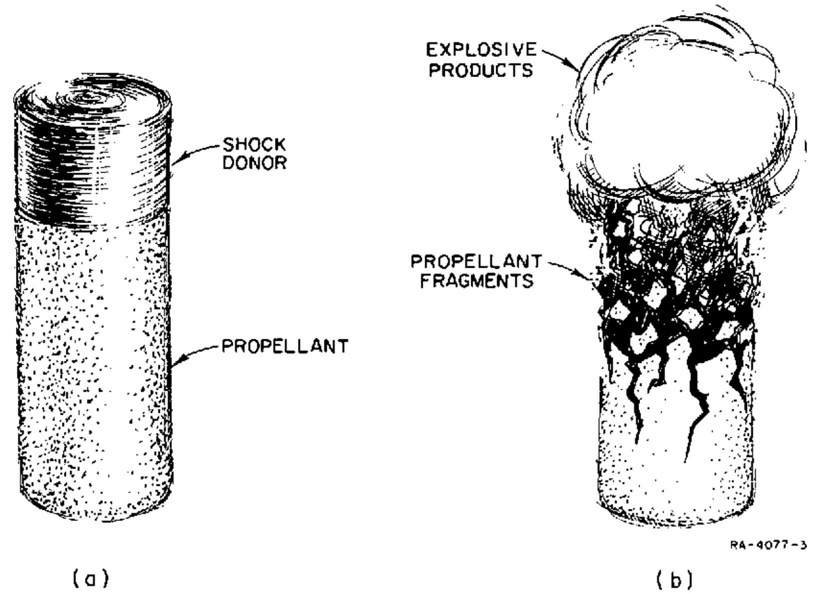

FIG. 3 PROPELLANT SHATTERING

Critical-diameter studies should be continued. There is, at the present time, a significant amount of work being conducted at various institutions aimed at developing models for the transition to stable detonation of shocked propellants or propellant ingredients.[27, 28, 36] It has been proposed that some of these models are sufficiently advanced to warrant their being tested. Such tests, inasmuch as they would involve very-large-diameter samples, would be difficult and expensive to perform. Attention should be given to the possibility of applying the predictions of the hypotheses to systems more easily handled. Meanwhile, the theoretical work should continue; the tendency of such studies to become bogged down in computer operations should be scrupulously avoided. Whatever the theories, there are insufficient physico-chemical data to use in applying them. The results of high-temperature, high-pressure kinetic studies on propellants and ingredients are badly needed. Equally, equation of state data for combustion reactants and, in particular, products are required.

The problem of duplicating a H_2-O_2 explosion is discussed briefly elsewhere. Such studies are needed badly and should include measurement of time-pressure profiles within and beyond the combustion zone. Particularly intriguing is the possible use of O_3F_2 in the oxygen to reduce the shock hazard significantly.[37]

Finally, little progress has been made in substituting, for current methods, the far more precise and significant results of improved temperature-stability tests, though these have been defined. That these methods can be performed routinely on a laboratory scale, obviating the large and expensive bonfires, is only one attribute. Their ability to predict hazards of storage is of inestimably greater value. Still largely unexplored is their possible application to the detection and monitoring of chemical degradation accompanying long-term storage. Continued research should be undertaken to provide the kinetic data required for application of the theory. The research should include experimental studies on rocket propellants and both experimental and theoretical studies (including development of mathematical models) of the effect of grain geometry.

PART FOUR: BIBLIOGRAPHY

The following is a list of miscellaneous references collected during work on this report. Many of these references do not deal with hazard classification of solid rocket propellants, but are of related interest. The references are listed in alphabetical order according to the company or place where the work was done. Wherever possible the company or agency report number, the Armed Services Technical Information Agency number (ASTIA AD number), and the Solid Propellant Information Agency file number have been included to facilitate acquisition.

A list of subject headings is at the beginning of the bibliography. These are numbered, and the numbers have been assigned to the report references to which they apply. These subject categories have been chosen and applied arbitrarily to the reports in the bibliography. They are not meant to be definitive, but should give the reader an indication of the kinds of information contained in the reports.

SUBJECT HEADINGS

Basic and General Knowledge

1. Shock Sensitivity (Gap Tests, Booster Tests, Hydronamic Shock)
2. Blast Effects
3. Thermal Stability (Self-heating, Autoignition)
4. Impact Sensitivity
5. Fragment, Bullet Sensitivity
6. General

Existing Methods for Hazard Evaluation

7. Fire and Thermal Hazards
8. Drop, Mechanical Shock
9. Fragment, Bullet
10. Nearby Blast
11. Shock Sensitivity
12. Instrumentation and Facilities
13. General

Motor Design Effects

14. Geometry, Critical Diameter
15. Weight
16. Propellant Composition
17. Confinement
18. Number of Segments
19. General

Conditions - Potential Hazards

20. Shipment, Transportation
21. Checkout and Storage
22. On Launch Stand, Prelaunch
23. Immediate Post-Launch
24. General

Applications - Particular Systems

25. Small
26. Redeye
27. Polaris
28. Minuteman
29. Large
30. General

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Appendix A

The following is Section III of the ASESB-proposed "Explosives Hazard Classification Procedure," which is the section dealing exclusively with classification of rocket motors and propellants. The reader is cautioned that the document is tentative and, as yet, has no official status.

SECTION III

Introduction to Minimum Test Criteria for Solid Propellants and Rocket Motors or Devices Containing Solid Propellants

7. This section establishes uniform criteria for tests from which hazard classifications and hazard characteristics of solid propellants (excluding gun type propellants) and rocket motors or devices containing solid propellants may be determined. The use of these criteria will assure the assignment of a uniform classification to any propellant, rocket motor or device by all Services or agencies.

8. a. This section defines and establishes specific tests, divided into phases, which must be performed to provide information for determining the hazard characteristics of solid propellants or rocket motors or devices containing solid propellants. The characteristics determined by these tests will be utilized to decide:

(1) That solid propellants are prohibitive or acceptable for transportation in small quantities (see Table VII).

(2) That larger quantities of propellant and rocket motors or devices are acceptable for transportation as Class A items (see Table VII).

(3) That ICC classification can be reduced to Class B.

(4) Military classification.

(5) What additional hazard characteristics are existent to both rocket motors or devices and assembled weapons containing solid propellants.

b. This section establishes criteria for performance of tests and evaluation of test results. These results will provide a basis for determining allowable handling procedures during development, testing, and production of solid propellants, developmental rocket motors or devices, and operational rocket motors or devices. Further discussion of the purpose of the individual tests, evaluation of the results and conclusions are included in the individual phases.

c. Tests of new items and applications: Phases I, II and III tests are mandatory (except for e below) and must be performed on solid propellants and rocket motors or devices containing these solid propellants. Tests in Phase IV are to be conducted at the option of the agency using the motor or device, and any or all tests in Phase IV can be made mandatory by that agency.

d. Tests of existing operational items: Phases I and II tests are not mandatory. Phase III tests are mandatory where true hazard classification has not been determined or is doubtful. Phase IV tests are optional.

e. Limited quantity research items not scheduled for standard Service use: such items are exempt from the mandatory requirement for Phase III testing where, with ICC concurrence, the Services wish to accept the highest appropriate hazard classification.

9. The determination of hazard characteristics is required prior to shipment of any solid propellant in commerce. (NOTE: A propellant is not required to undergo hazard classification tests unless propellant is to be stored or shipped.) The test program is divided into four phases as outlined in Table VII. The results of the tests yield the information from which hazard characteristics are determined. The phases of these criteria are designed to coincide with the various stages of propellant development from synthesis to use in a rocket motor or device. Further, since hazards during transportation and storage are, at times, influenced by configuration, tests in Phases III and IV will, as far as possible, consider programmed or likely storage and shipping configurations and environments. The assignment of hazard classifications is made at specified intervals during the test program.

10. The test criteria given in this document are considered to be valid for the purposes intended; however, new tests are being developed and modifications of some of the tests given are being considered. These criteria will be periodically revised or supplemented to include any additional information which may provide additional bases for determining the hazards of solid propellants and rocket motors or devices.

11. Phase I is divided into two categories:

a. Category A tests will be conducted while the quantity of propellant is within the limits specified in Phase I-A of Table VII. Results of these tests will permit determination of conditions under which small propellant samples may be shipped subject to Interstate Commerce Commission regulations.

b. Category B tests, which are conducted when sufficient propellant becomes available, are to be performed to permit shipment of larger quantities of bulk propellant (unconfined - not in motor or device case) in accordance with Interstate Commerce Commission regulations.

12. Phases II and III will be conducted before the classification of the end item (rocket motor or device) is lowered from a detonation to fire hazard. Phase II tests are performed to predict the hazard characteristics of full scale motors or devices. Phase III tests use full scale end items to determine the validity of predictions resulting from Phase II tests. Until it can be determined by the responsible agencies that the predictions from Phase II tests are valid for full scale motors or devices, the results of Phase III tests will be used for assigning hazard classifications.

13. Phase IV tests utilize various assembled configurations. It is intended to inter-relate the effects of individual components (i.e., single stage detonation, warhead detonation, etc.) to the reaction of the complete configuration. The

TABLE VII

TEST PHASE	I	II	III	IV
STAGE OF DEVELOPMENT	Laboratory Development	Propellant Development	Motor Development	Complete Missile
CHARACTERISTIC WORK AREA	Synthesis & Propellant Performance	Ballistic Modification Sub-Scale Tests	Full Scale Motor or Device	Advance Production Missile
ITEM OR QUANTITY PRODUCED	A few pounds of propellant	From a few pounds of propellant to full scale motor	Full scale motor or device	Complete Missile
PURPOSE OF TESTS	I-A To determine if ½ pound lab sample can be shipped by commercial transportation I-B To determine if quantities larger than ½ pound lab samples can be shipped by commercial transportation	To determine detonability and relative sensitivity of confined propellant in sizes smaller than full scale motors	To determine ICC and storage classification of full scale motors or devices	To determine: a) ICC and storage class of complete missile b) TNT equivalency of a system c) Quantity-distance requirements for system d) Any special hazards
TESTS	I-A (Propellant Sample) 1. Detonation 2. Ignition 3. Thermal stability 4. Impact sensitivity 5. Differential thermal analysis I-B (2-inch cube) 1. Detonation 2. Thermal stability	1. Critical diameter 2. Card gap 3. External heat 4. Bullet impact	1. Drop test 2. External heat 3. Bullet impact 4. Detonation	1. Detonation test of two identical motors 2. Detonation test of multi-stage missile 3. Detonation test of missile with warhead 4. Detonation test of missile with destruct system 5. External heat test
ICC AND MILITARY CLASSIFICATION	I-A ICC - Lab samples Class A Mil - Class 9 I-B ICC - Class A or B Mil - Class 9 or 2	ICC - Class A Experimental rocket motor Mil - Class 10	ICC - Class A or B Mil - Class 10 or 2	ICC - Class A or B Mil - Class 10 or 2
MAXIMUM QUANTITY SHIPPABLE	I-A - ½ pound lab samples I-B - Unlimited bulk propellant (unconfined - not in rocket motor or device)	Developmental motors less than full scale	Full scale motors or devices	Complete missile system

results will dictate the hazard classification; however, the hazard classification for the complete configuration need not be as high as that of any single component if the lower hazard classification presents greater hazards. (Such a condition would exist with a small warhead and a very large fire hazard motor or a fire hazard motor shipped with a Class A igniter.)

14. Reject motors or devices may be used in Phase III and IV tests if reasons for rejection would not materially affect test results.

NOTE: During all the test phases, extreme caution shall be observed. Strict safety procedures shall be enforced. The suggested procedures for initiating fires on high explosives may be modified if they do not alter the test results.

Phase I Tests - Mandatory

15. Introduction.

The first phase of the hazard classification test is conducted on laboratory size samples of propellants which are undergoing research. When conducting these tests, start with the smallest sample possible to accomplish the particular test. Two categories are available in this phase:

a. Category A utilizes test samples in the order of grams. The tests are designed to compare the sensitivity of the propellant with that of initiating explosives. If the propellant is less sensitive than initiating explosives, then it may be shipped in quantities up to ½ pound to allow other agencies to conduct laboratory evaluation studies subject to section 73.86 of the Interstate Commerce Commission regulations.

b. Category B tests are conducted when the propellant becomes available in larger quantities. The tests are essentially the minimum required to determine

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whether large quantities of propellant may be shipped in accordance with Interstate Commerce Commission regulations.

c. The Interstate Commerce Commission (Bureau of Explosives, AAR) reserves the right to require samples of propellants to be submitted for testing, if required, and/or to witness tests.

16. <u>PHASE I - Category A Tests.</u>

If the detonation and thermal stability tests in Phase I-A are conducted on 2-inch samples of the propellant, the Phase I Category B tests need not be performed.

a. The following equipment is required for these tests:

(1) One (1) Bureau of Explosives impact apparatus. Drawings are available at the Bureau of Explosives, Association of American Railroads, 63 Vesey Street, New York 7, New York.

(2) One (1) ventilated oven capable of maintaining a temperature of 75°C or above for a period of 48 hours. The oven will be equipped to continuously record the temperature.

(3) One (1) oven capable of temperature rise of 10°C per minute between 25°C and 500°C and equipped to continuously record the temperature.

(4) Number 8 and Engineer Special Electric Blasting Caps (J-2) as required.

(5) One (1) blasting machine.

(6) Kerosene-soaked sawdust sufficient for four (4) beds, 1 foot square and $\frac{1}{4}$ inch thick.

(7) Electric match-head igniters as required.

(8) Solid lead cylinders $1\frac{1}{2}$ inch diameter by 4 inches high as required.

(9) One (1) piece of mild steel plate, $\frac{1}{2}$ inch thick by 12 inches square or its equivalent.

(10) One (1) temperature block for testing 20 mg samples.

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b. The test samples to be used in Phase I-A are to be at least 10 grams in weight; however, they should not be larger than the sizes given in the following list:

(1) Seventeen (17) propellant samples 2 inches $\pm \frac{1}{4}$-inch cubes.

(2) Two (2) propellant samples 1 inch $\pm$ 1/8-inch cubes.

(3) Twenty (20) 10 mg propellant samples suitable for use in the Bureau of Explosives impact apparatus.

(4) One (1) 20 mg propellant sample.

(5) One (1) 20 mg sample of alundum 90 mesh.

c. Detonation Test.

(1) Place one (1) lead cylinder (2a8) upon the steel plate (2a9). Place a Number 8 blasting cap (2a4) perpendicular to and in contact with a flat surface of a convenient quantity of propellant, but not less than 10 grams or one of the 2-inch samples (2b1) which is then placed on top of the lead cylinder. While observing appropriate safety regulations, fire the cap. Deformation or mushrooming of the lead cylinder will be considered as evidence of detonation. Conduct this test a maximum of five (5) times, or until detonation occurs, whichever is the least number of tests.

(2) Observers will record data required on Report Form 1 opposite Detonation Test.

d. Ignition and Unconfined Burning Test.

(1) Place a 1-inch sample (2b2) on a single bed of kerosene-soaked sawdust (2a6) and ignite the sawdust with an electric match-head igniter (2a7).

(2) Place a 2-inch sample (2b1) on a single bed of kerosene-soaked sawdust (2a6) and ignite the sawdust with an electric match-head igniter (2a7). Repeat this test one (1) time.

(3) Place four (4) 2-inch samples end-to-end in a single row in contact with each other on a single bed of kerosene-soaked sawdust (2a6) and ignite the sawdust with an electric match-head igniter (2a7).

(4) Observer will record results on Report Form 1 opposite Ignition and Unconfined Burning Test.

e. Thermal Stability Test.

(1) Place any convenient quantity of propellant, but no less than 10 grams or one (1) 1-inch sample (2b2) in constant temperature oven (2a2). Raise the temperature of the oven to 75°C and maintain the temperature at 75°C or above for a period of 48 hours. These temperatures shall be continuously recorded. Constant observation is not required.

(2) Record results on Report Form 1 opposite Thermal Stability Test.

f. Impact Sensitivity Test (to be conducted only if detonation occurs in Test "c").

(1) Conduct twenty (20) individual tests using one (1) sample (2b3) per test in the Bureau of Explosives impact apparatus (2a1).

(2) Perform tests and observe results to supply data as required on Report Form 1 opposite Impact Sensitivity.

(3) Use cleaning equipment as required to thoroughly clean and dry the anvil and cup assemblies of the impact apparatus prior to each test. Apparatus must be at ambient temperature prior to each test.

g. Differential Thermal Analysis Test.

(1) Place the 20 mg propellant sample (2b4) and the sample of alundum (2b5) separately in the temperature block (2a10) instrumented with thermocouples to determine the individual traces of temperature versus time of propellant and alundum simultaneously. The block is placed in the oven (2a3) at 25°C and the oven

temperature raised to 500°C at the rate of 2°C to 5°C per minute. Temperatures of both samples are recorded continuously during the entire test.

(2) The extent of exothermic or endothermic reaction of the propellant is determined by comparing propellant and alundum temperature recordings.

17. PHASE I - Category B Tests.

If the detonation and thermal stability tests in Phase I-A were conducted on 2-inch samples of the propellant, Test 1-B need not be performed. However, if test samples for these tests used in Phase I-A were smaller than 2-inch cubes, Phase I-B tests will be performed using 2-inch cube samples.

a. Detonation Test.

(1) Place one (1) lead cylinder (2a8) upon the steel plate (2a9). Place a Number 8 blasting cap (2a4) perpendicular to and in contact with a flat surface of one of the 2-inch samples (2b1) which is then placed on top of the lead cylinder. While observing appropriate safety procedures, fire the cap. Deformation or mushrooming of the lead cylinder will be considered as evidence of detonation. Conduct this test a maximum of five (5) times or until detonation occurs, whichever is the least number of tests.

(2) For military evaluation, if no detonation occurs in 3a(1), repeat 3a(1) but replace the Number 8 blasting caps with Engineer Special Electric Blasting Caps (J-2) (Phase I-A, Item 2a4).

(3) Observer will record data required on Report Form 1 opposite Detonation Test.

b. Thermal Stability Test.

(1) Conduct the test in the same manner as described under Phase I-A, (Test e(1)) except sample size for present test is 2-inch.

(2) Observer will record results on Report Form 1 opposite Thermal Stability Test.

temperature raised to 500°C at the rate of 2°C to 5°C per minute. Temperatures of both samples are recorded continuously during the entire test.

(2) The extent of exothermic or endothermic reaction of the propellant is determined by comparing propellant and alundum temperature recordings.

17. <u>PHASE I - Category B Tests.</u>

If the detonation and thermal stability tests in Phase I-A were conducted on 2-inch samples of the propellant, Test 1-B need not be performed. However, if test samples for these tests used in Phase I-A were smaller than 2-inch cubes, Phase I-B tests will be performed using 2-inch cube samples.

a. Detonation Test.

(1) Place one (1) lead cylinder (2a8) upon the steel plate (2a9). Place a Number 8 blasting cap (2a4) perpendicular to and in contact with a flat surface of one of the 2-inch samples (2b1) which is then placed on top of the lead cylinder. While observing appropriate safety procedures, fire the cap. Deformation or mushrooming of the lead cylinder will be considered as evidence of detonation. Conduct this test a maximum of five (5) times or until detonation occurs, whichever is the least number of tests.

(2) For military evaluation, if no detonation occurs in 3a(1), repeat 3a(1) but replace the Number 8 blasting caps with Engineer Special Electric Blasting Caps (J-2) (Phase I-A, Item 2a4).

(3) Observer will record data required on Report Form 1 opposite Detonation Test.

b. Thermal Stability Test.

(1) Conduct the test in the same manner as described under Phase I-A, (Test e(1)) except sample size for present test is 2-inch.

(2) Observer will record results on Report Form 1 opposite Thermal Stability Test.

18. Conclusions.

a. The following conclusions may be derived from Phase I Category A test results (small quantity):

(1) ICC Prohibited Explosives, if any one of the following occurs:

(a) Thermal stability test results in either a detonation, burning or marked decomposition.

(b) Propellant samples with a drop sensitivity of less than 4 inches will not be shipped until shipping instructions have been requested and received from the Interstate Commerce Commission.

(2) ICC Permitted (labeled as laboratory sample) (Military mass-detonating) if any one of the following occurs:

(a) Detonation test produces a detonation.

(b) Ignition test produces a detonation.

(c) Detonation test produces a detonation; and impact sensitivity test produces a detonation above 4 inches of drop height. (12 inches is considered to be a practical maximum drop height.)

(d) Detonation test produces either burning of propellant or no reaction (other than fragmentation); ignition test results in propellant burning and thermal stability test does not result in detonation, burning or marked decomposition.

(3) At the conclusion of Phase I Category A, the lowest classification to be assigned is ICC Laboratory Samples and Military mass-detonating. Propellant shall be labeled as Laboratory Samples and shipped in accordance with section 73.86 of the ICC regulations.

b. The following conclusions may be drawn from Phase I Category B tests (2-inch cube):

18. Conclusions.

a. The following conclusions may be derived from Phase I Category A test results (small quantity):

(1) ICC Prohibited Explosives, if any one of the following occurs:

(a) Thermal stability test results in either a detonation, burning or marked decomposition.

(b) Propellant samples with a drop sensitivity of less than 4 inches will not be shipped until shipping instructions have been requested and received from the Interstate Commerce Commission.

(2) ICC Permitted (labeled as laboratory sample) (Military mass-detonating) if any one of the following occurs:

(a) Detonation test produces a detonation.

(b) Ignition test produces a detonation.

(c) Detonation test produces a detonation; and impact sensitivity test produces a detonation above 4 inches of drop height. (12 inches is considered to be a practical maximum drop height.)

(d) Detonation test produces either burning of propellant or no reaction (other than fragmentation); ignition test results in propellant burning and thermal stability test does not result in detonation, burning or marked decomposition.

(3) At the conclusion of Phase I Category A, the lowest classification to be assigned is ICC Laboratory Samples and Military mass-detonating. Propellant shall be labeled as Laboratory Samples and shipped in accordance with section 73.86 of the ICC regulations.

b. The following conclusions may be drawn from Phase I Category B tests (2-inch cube):

(1) Prohibitive.

(a) Thermal stability test Phase I-A or I-B results in either a detonation, burning or marked decomposition of propellant.

(b) Propellants with a drop sensitivity of less than 4 inches in Phase I-A or I-B will not be shipped until shipping instructions have been requested and received from the Interstate Commerce Commission.

(2) ICC Class A (Propellant) - (Military Class 9*).

(a) Detonation test Phase I-A or I-B produces a detonation.

(b) Detonation test Phase I-A or I-B produces a detonation; and impact sensitivity test Phase I-A or I-B produces a detonation above 4 inches of drop height.

(3) ICC Class B (Propellant) - (Military Class 2 if unconfined
Military Class 9 if confined)

(a) Detonation test Phase I-A or I-B does not result in a detonation and thermal stability test Phase I-A or I-B does not result in detonation, burning or marked decomposition.

* Bulk propellant (unconfined - not in rocket motor or device) may be classified as ICC Class B (Propellant) or Military Fire Hazard (Class 2) based upon Phase I-A and I-B test. The classification of confined propellants shall not be lowered at this time as all tests in Phase I-A and I-B are unconfined and tests in Phases II and III must be conducted prior to lowering ICC or Military classifications from Detonation (Class 9) to Fire Hazard (Class 2). Containers loaded with propellant samples for test purposes will be considered as ICC Class A and may be shipped upon ICC approval. Drawings of shipping containers which may be used for the Phase II test samples and which have been ICC-approved are available from the ASESB, Room 2075, Building T-7, Gravelly Point, Washington 25, D. C.

[redacted]

Form No. 1

HAZARD & STABILITY TEST REQUIRED FOR ICC CLASSIFICATION

Test for ICC Classification	Propellant Identity (Type No.)	Batch	Date
Spec:			

Detonation Test

		Detonated Yes 1A	Detonated Yes 1B	Detonated No 1A	Detonated No 1B	Burned Yes 1A	Burned Yes 1B	Burned No 1A	Burned No 1B	Fragmented Yes 1A	Fragmented Yes 1B	Fragmented No 1A	Fragmented No 1B
No. 8 Blasting Cap	Test I												
	Test II												
	Test III												
	Test IV												
	Test V												

		Detonated Yes	Detonated No	Burned Yes	Burned No	Fragmented Yes	Fragmented No
Engineers Special Blasting Cap	Test I						
	Test II						
	Test III						
	Test IV						
	Test V						

Samples: Ten (10) 2-inch cubes   Test: One blasting cap in well of each sample

Ignition & Unconfined Burning Test

	Detonates Yes	Detonates No	Average Burning Time Seconds
One (1) 1-inch cube			
One (1) 2-inch cube No. 1			
One (1) 2-inch cube No. 2			
Four (4) 2-inch cubes			

Samples: One (1) 1-inch & Six (6) 2-inch cubes   Test: Ignite & burn unconfined

Thermal Stability Test

	Ignition Yes	Ignition No	Change in Configuration Yes	Change in Configuration No
One (1) 1-inch cube				
One (1) 2-inch cube				

Samples: One (1) 1-inch cube & One (1) 2-inch cube   Test: 48 hours at 75°C or above, in vented oven

Impact Sensitivity Test

Bureau of Explosives Impact Apparatus

Ten 3-3/4" (± 1/16") Drop Test			Ten 10" (± 1/16") Drop Test		
Explosion Flame and Noise No.	Decomposition Smoke No Noise No.	No Reaction No Smoke No Noise No.	Explosion Flame and Noise No.	Decomposition Smoke No Noise No.	No Reaction No Smoke No Noise No.

Differential Thermal Analysis Test

Exothermic Yes	Exothermic No	Endothermic Yes	Endothermic No

NOTE: If exothermic, include plot of temperature versus time

ICC Classification   Propellant Explosives Class A _____   Req ICC Approval _____

Test Director __________   Test Dept. Head __________

Bureau of Explosives Representative __________

Military Representative __________

(Army, Navy or Air Force)   1 May 1952

NOTE: Copies of this form to be submitted to Service responsible for test administration as well as to the Distribution list given in paragraph 4e.

[redacted]

Phase II Tests - Mandatory

19. Introduction.

a. This phase of testing is intended to determine the sensitivity of solid propellants. These tests are to be conducted on motors smaller than full size and on propellants in specific test apparatus. The critical diameter tests will determine the detonation susceptibility of the propellant at dimensions less than or equal to eight (8) inches, with a specified booster. An estimation of contribution of the propellant to blast pressures is desirable and may also be obtained from the 8-inch critical diameter test. The card gap test at zero cards will be used for the 2-inch critical diameter tests; if detonation occurs, then the card gap test will be continued to determine sensitivity. The card gap test will provide information on the relative sensitivity of various propellants. The external heat test will provide information on the behavior of a motor or device when subjected to an accident involving this hazard. The bullet impact test is designed to furnish information regarding hazards from fragments and rifle fire.

b. Standard pentolite donor charges are manufactured for all Services by the Department of the Navy. Information regarding these charges is available from the Chief, Bureau of Naval Weapons, Department of the Navy, Washington 25, D. C., Attention: F-12.

c. The results of these tests are to be given in a narrative report including photographs of set-up and results, charts or diagrams, and recommendations. Such reports are to be furnished to the Service responsible for test administration, as well as to the distribution list given in paragraph 4e.

20. The following equipment items are required:

a. Cold-rolled seamless tubing.

(1) One (1) 16-inch length of 4-inch ID pipe 3/8-inch wall thickness.

(2) One (1) 32-inch length of 8-inch ID pipe 3/4-inch wall thickness.

(3) Mild steel tubing 1.437-inch ID and 1.87-inch OD as required.

(4) Two (2) 5-inch "work horse" test motors.

b. Mild steel witness plates.

(1) One (1) piece 8 x 8 x ½ inch.

(2) One (1) piece 12 x 12 x 1 inch.

(3) Pieces of 6 x 6 x 3/8 inch as required for card gap test.

c. Cellulose acetate cards 0.010 inch thick and diameter equal to sample as required for card gap tests.

d. Engineers Special Electric Blasting Caps (J-2).

e. The samples of propellant and booster for the critical diameter tests and card gap test are described in paragraphs 3 and 4 below.

f. The donor charge for the critical diameter test is to be of cast 50/50 pentolite with the diameter, length and shape as given in paragraphs 3a and 4a below.

21. Critical Diameter Tests.

a. The 4-inch propellant grain will be tested first. The tests are concluded if the 4-inch diameter charge sustains a detonation. The propellant sample as well as the pentolite booster to be temperature conditioned to approximately 25°C.

Test Scale**	Propellant Grain Size	Booster Size	Witness Plate
4 inch	4 inch diameter 16 inch length	4 inch diameter cone 12 inch length	8" x 8" x ½"
8 inch	8 inch diameter 32 inch length	8 inch diameter cone 24 inch length	12" x 12" x 1"

** Critical diameter test may be concluded at 8" or diameter of end item, whichever is the lesser.

The propellant grain is cast or inserted into the pipe without a liner and ends trimmed flush.

b. The components of the tests are placed in a fixture in the following order: the pipe containing the propellant is fixed in a vertical position and the witness plate placed on bottom of the tube, separated by 1/16-inch air gap. (NOTE: The witness plate should not rest on ground surface.) The pentolite booster is placed at the top of the tube in contact with the propellant.

c. The booster is initiated by an Engineers Special Electric Blasting Cap (J-2). Detonation is indicated when a clean hole is cut in the witness plate.

d. On the 8-inch sample test, instrumentation may be placed in two radial arrays to record air blast overpressure, located as determined by calibration tests. In the event detonation does not occur, contribution to air blast by the propellant can be determined from the instrumentation. Results are to be reported in terms of psi overpressure versus distance and in TNT equivalents.

22. Card Gap Test.

a. The set-up for the card gap test is shown in Figures 1 and 2. The propellant sample is cast or placed inside of a cold-rolled steel tube having a 1.437-inch ID and 1.875-inch OD by 5.5 inches long. The booster will be a 50/50 pentolite cylinder having a diameter of 2 inches and a length of 2 inches, composed of two (2) 2-inch diameter by 1-inch long pellets. (See Appendix A.) The attenuation cards used are 0.01-inch cellulose sheet or equivalent lucite. A mild steel witness plate 6 inches square by 3/8-inch thick is used to record test results and is placed on top of the propellant sample but separated by 1/16-inch air gap. These tests are to be conducted with the propellant sample and booster temperature of approximately 25°C.

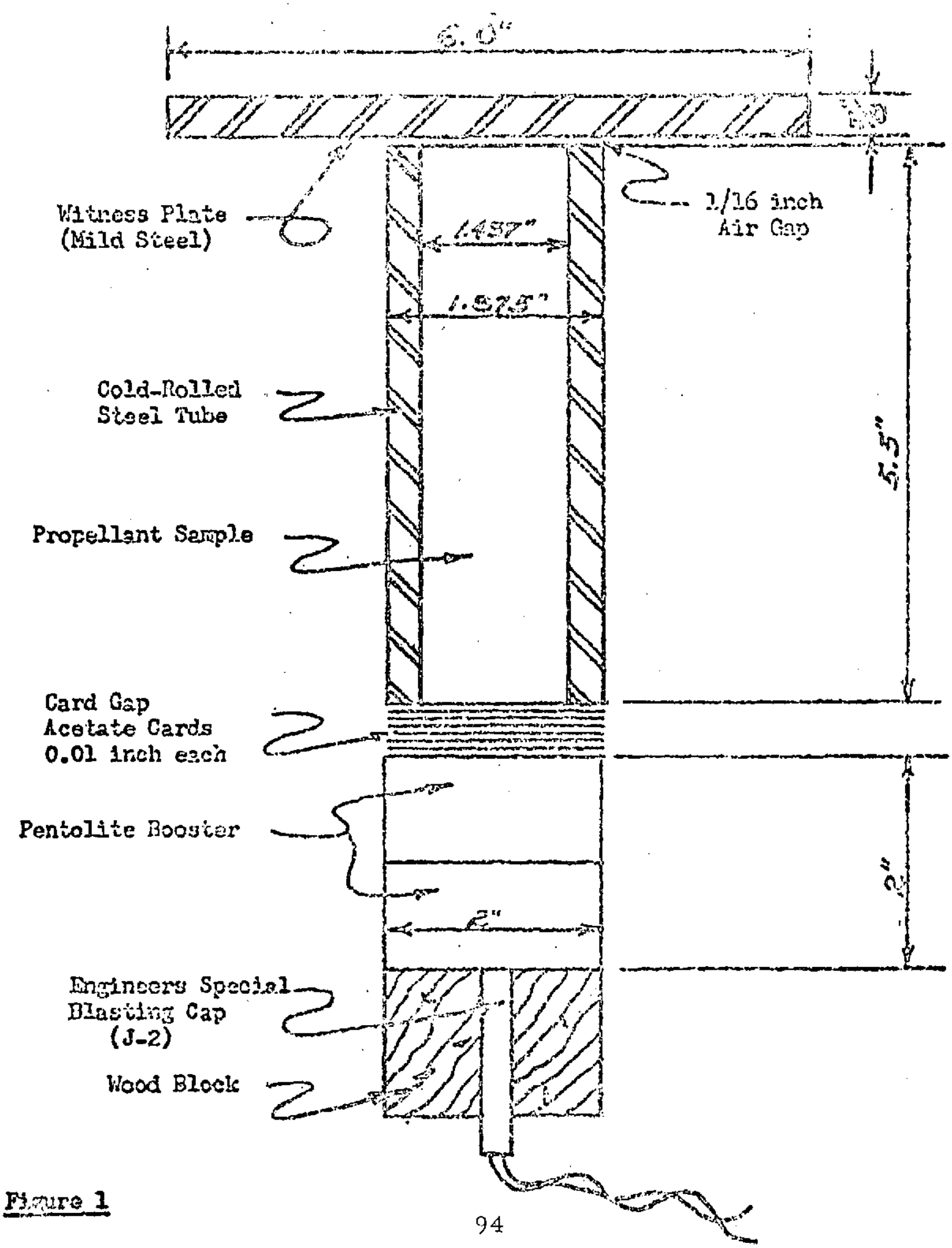
6.0"
Witness Plate
(Mild Steel)
1/16 inch
Air Gap
1.437"
1.875"
Cold-Rolled
Steel Tube
5.5"
Propellant Sample
Card Gap
Acetate Cards
0.01 inch each
Pentolite Booster
2"
2"
Engineers Special
Blasting Cap
(J-2)
Wood Block

Figure 1

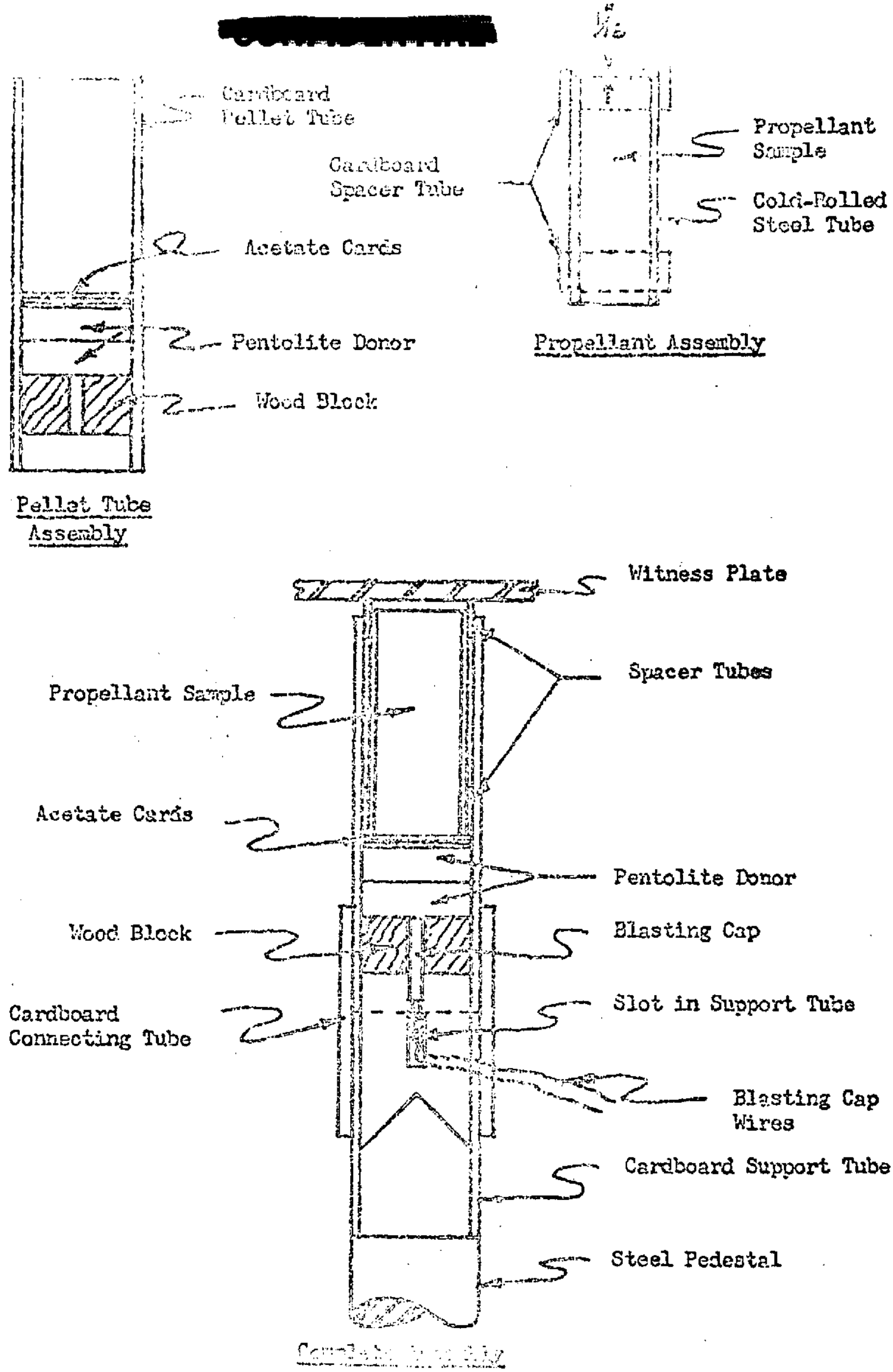

Figure 2 CHARGE ASSEMBLY

b. The test will be conducted using zero cards for first test. If a detonation occurs, the next test will be conducted at 8 cards; if detonation occurs, the next test will be conducted at 16 cards, etc. If a detonation is not obtained, drop number of cards to half the value to the nearest detonation. Example: detonation at 32 cards, no detonation at 64 cards. The next test should be conducted at 48 cards. If detonation occurs at 48 cards, the next test will be conducted at 56 cards, etc. until 50% point is obtained. If it is known that similar materials have a 50% value of a given number, for example, 75 cards, there is no necessity of starting at zero cards.

c. The criterion of "detonation" used is the punching of a clean hole in the witness plate. The measure of charge sensitivity is the length of attenuation (gap length) at which there is 50% probability of detonation according to the above criterion. The charge sensitivity is usually expressed in terms of number of 0.01-inch cards necessary for the 50% value between detonation and no detonation. Normally, a maximum of 12 tests will be required to determine the 50% value. (See references 1 through 7.)

23. <u>External Heat Tests.</u>

a. Equipment.

(1) Sufficient lumber or diesel fuel to sustain burning for a minimum of 30 minutes. In determining quantity of lumber or fuel, it must be considered that burning area should be sufficient to heat entire underside of test motor. If lumber is selected for test, it should be soaked sufficiently with fuel oil to assure thorough ignition and rapid burning of lumber.

(2) Two (2) 2-ounce bags of Class 2 smokeless powder.

(3) Two (2) electric squibs.

(4) Color motion picture cameras of 16 or 24 frames per second to record entire duration of test.

(5) Instrumentation, of any reliable type, to record peak blast pressures at various distances from the test (minimum of six positions).

(6) Instrumentation of reliable type such as paint tape or recording equipment to record peak temperatures at various distances from rocket motor (minimum of six positions).

(7) Equipment, as available, for restraining rocket motor during test.

b. Test Item.

(1) One (1) 5-inch diameter simulated motor ("work horse").

c. Test Procedure.

Adequately restrain the test rocket motor in a horizontal position. Instrument rocket motor for recording chamber pressure versus time. Position instrumentation for recording air blast overpressures and temperatures in two radial arrays located as determined by calibration tests, and at a height compatible with test set-up. Locate movie cameras at angles to view aft end and opposite sides of motor. Place fuel oil or lumber of required quantity beneath rocket motor in a fashion to heat complete underside of motor. Insert squibs into bags of smokeless powder and locate bags so as to ignite the fuel oil or lumber on opposite sides of the motor. Start camera and instrumentation at time of initiation of squibs. Should detonation, explosion, or pressure failure result, a fragment dispersion pattern shall be made. This pattern should include, but not necessarily be limited to, fragment material, size, and distance projected.

24. <u>Bullet Impact Test.</u>

a. Equipment.

(1) One (1) round of .50 caliber or 20mm AP service velocity ammunition.

(2) Instrumentation as available to record air blast overpressure and temperature, located as determined by calibration tests.

(3) Two (2) cameras of 16 or 24 frames per second and two (2) high-speed cameras to record in color motion pictures the entire test from two (2) positions.

b. Test Item.

(1) One (1) 5-inch diameter simulated motor ("work horse").

c. Test Procedure.

Adequately restrain the test rocket motor in a horizontal position. The gun used is to be located at a firing distance of approximately 100 feet and normal to the side of the rocket motor and suitably protected in event of a detonation. Instrumentation for recording peak blast pressure shall be located in two radial arrays located as determined by calibration tests, and aboveground at a height compatible with the test set-up. Color motion pictures shall be taken of the complete test at 16 or 24 frames per second plus high speed. Fire either the 20mm or .50 caliber AP projectile into the rocket motor. If a detonation, deflagration or pressure rupture occurs, the size and depth of crater shall be measured. Record peak blast pressure readings, and a fragmentation map shall be prepared indicating distance, direction and weight of both steel and propellant fragments, as well as locations where propellant fragments burned.

25. Conclusions.

Classification based on Phase II tests.

a. Military mass-detonating.

(1) Critical diameter test has resulted in a detonation and card gap test has determined a detonation sensitivity value of 70 or more cards.

(2) External heat test has resulted in a detonation.

(3) Bullet impact test has resulted in a detonation.

(4) Phase I testing has categorized the propellant as ICC Class A (Military Class 9) regardless of results of Phase II testing.

b. Military fire hazard.

(1) Critical diameter test has resulted in no detonation.

(2) Critical diameter test has resulted in a detonation and card gap test has determined a detonation sensitivity value of less than 70 cards.

(3) External heat test has not resulted in a detonation.

(4) Bullet impact test has not resulted in a detonation.

(5) Phase I tests have not categorized the propellant as either prohibited or ICC Class A (Military Class 9).

<u>Phase III Tests - Mandatory</u>

26. <u>Introduction.</u>

This phase is intended to determine actual hazard characteristics of full scale rocket motors*** or devices selected for end item, the associated hazard classification, and the required quantity-distance that is required for safety. This phase will demonstrate the actual hazards associated with a rocket motor or device when exposed to detonation, fragment penetration, fire and drop. Further, only upon the completion of this phase of testing, and when the results indicate essentially only a fire hazard, can the Interstate Commerce Commission classification be changed from A to B and Military classification be changed from 10 to 2. An analysis of the results of the tests which indicate that a motor should be Class B (2) will determine the quantity-distance required based on fragment and propellant dispersion as well as radiant heat produced. Reject motors may be used for these tests if reasons for rejections will not materially affect test results. It is recommended that a post test infra-red still picture be made of the test area. The altitude from which this picture is taken should be sufficient to include the farthest distance fragments are thrown. It has been found that an infra-red picture will be of considerable value in preparing a fragment map as all hot fragments, as well as locations where propellant fragments burned, will readily show up on such a picture. It is the intent of these tests to obtain the actual hazards of the items being tested; therefore, small items for which there is sufficient safety area should not be restrained. Test reports should indicate if restraint was used. The results of these tests are to be given in a narrative report including photographs of set-up and results, charts or diagrams and recommendations. Such reports are to be furnished to the Service responsible for test administration as well as to the distribution list given in paragraph 4e.

*** For segmented grain motors, one head segment, one center segment, and one aft aft segment shall be considered as a full size motor. If desired, grains of full diameter and a L/D of 3 to 1 with forward and aft closures may be used for these tests.

27. Test equipment required for each test is listed below for each test.

28. The number and type of samples required for each test are specified below for each test.

29. External Heat Test.

a. Equipment.

(1) Sufficient lumber or diesel fuel to sustain burning for a minimum of 30 minutes. In determining quantity of lumber or fuel, it must be considered that burning area should be sufficient to heat entire underside of test motor. If lumber is selected for test, it should be soaked sufficiently with fuel oil to assure thorough ignition and rapid burning of the lumber.

(2) Two (2) 2-ounce bags of Class 2 smokeless powder.

(3) Two (2) electric squibs.

(4) Color motion picture cameras of 16 or 24 frames per second to record entire duration of test.

(5) Instrumentation, of any reliable type, to record blast peak pressures at various distances from test (minimum of six positions).

(6) Instrumentation such as paint tape or recording equipment to record peak temperatures at various distances from rocket motor (minimmm of six positions).

(7) Instrumentation, of reliable type, for recording chamber pressure versus time during duration of test.

(8) Equipment, as available, for restraining rocket motor during test.

b. Test Item.

(1) One (1) full scale rocket motor or device, as shipped and/or stored.

c. Test Procedure.

Adequately restrain the test rocket motor or device in a horizontal position. Instrument rocket motor or device for recording chamber pre versus time. Position instrumentation for recording air blast overpressures and temperature in two radial arrays located as determined by calibration tests and aboveground level at a height compatible with test set-up. Locate movie cameras at angles to view aft end and opposite sides of motor or device. Place fuel oil or lumber of required quantity beneath the item in a manner to heat complete underside. Insert squibs into bags of smokeless powder and locate bags so as to ignite fuel oil or lumber. Start camera and instrumentation just prior to initiation of squibs. Should detonation, explosion, or pressure failure result, a fragment dispersion pattern shall be made. This pattern shall include, but not necessarily be limited to fragment material, size and distance projected.

30. Bullet Impact Test.

a. Equipment.

(1) One (1) round of .50 caliber or 20mm AP ammunition.

(2) Instrumentation of any reliable type to measure peak blast pressure and temperature along two radial arrays.

(3) Two (2) cameras of 16 or 24 frames per second and two (2) high-speed cameras to record in color motion pictures the entire test from two positions.

b. Samples.

(1) One (1) full scale rocket motor or device as shipped and/or stored.

c. Test Procedure.

The bullet impact test shall be conducted on one (1) full scale item. The item shall be restrained from movement in a horizontal position and placed in a suitable location sufficient for safety precautions in case a detonation occurs. The gun used is to be located at a firing distance of approximately 100 feet from and normal to the side of the item and suitably protected in event of a detonation. Instrumentation for recording peak blast pressure shall be located in two radial arrays at distances determined by calibration tests, and at a height compatible with the test set-up. Chamber pressure shall be measured. Color motion pictures shall be taken of the complete test at 16 or 24 frames per second plus high speed. Ample protection of the cameras shall be taken to prevent damage in case of a detonation. Fire either a 20mm or .50 caliber AP projectile into the rocket motor. If a detonation, deflagration, or pressure rupture occurs, the size and depth of crater shall be measured. Record peak blast pressure readings, and a fragmentation map shall be prepared indicating distance, direction, and weight of both steel and propellant fragments, as well as locations where propellant fragments burned.

31. <u>Detonation Test.</u>

a. Equipment.

(1) Motion picture cameras at 16 or 24 frames per second and high speed.

(2) Instrumentation, of any reliable type, to measure peak blast pressure and temperature along two radial arrays.

(3) Instrumentation to measure chamber pressure and thrust.

(4) Test stand or other equipment to restrain item during test.

(5) One (1) 50/50 pentolite booster 2-inch diameter by 2-inch length, and one (1) Engineers Special Electric Blasting Cap (J-2).

b. Test Item.

(1) One (1) full scale rocket motor or device, as shipped and/or stored. (Additional test should be conducted if motors or devices are available.)

c. Test Procedure.

The item will be adequately restrained. Instrumentation for measurement of chamber pressure will be installed. Peak air blast and temperature instrumentation will be installed in two radial arrays at distances determined by calibration tests and at a height compatible with the test set-up. Motion picture coverage will be installed to give coverage from two sides of motor or device. Insert the blasting cap into the pentolite booster. The booster assembly will then be placed inside of the motor or device and with the booster in intimate contact with the propellant. Adequate safety precautions will be taken to protect personnel and equipment should a detonation occur. Instrumentation and cameras should be started prior to initiation of the blasting cap. Should detonation, deflagration or pressure rupture occur, readings from the instrumentation shall be recorded, depth of crater measured, and a fragment map prepared showing material, size and distance projected.

32. <u>Drop Test.</u>

a. Equipment.

(1) Drop tower.

(2) One (1) motion picture camera capable of speed of 16 or 24 frames per second.

(3) Instrumentation of any reliable type for measuring peak blast pressures and temperature along two radial arrays.

(4) Concrete or steel pad.

b. Test Item.

(1) One (1) full scale rocket motor or device, less nozzles, without transportation or storage container. It is preferable to remove the nozzle of the test item or install a destruct device (see reference 8).

c. Test Procedure.

Elevate motor or device to a height which is the greater of the following: the maximum height to which a rocket motor might be hoisted during its normal transportation, handling or tactical environment. The maximum height necessary to satisfy this test requirement is 40 feet regardless of the above. Place instrumentation to record peak blast pressures at distances determined by calibration tests, and at a height compatible with test set-up. After the motor has been elevated to the proper height, it should be oriented in a horizontal attitude and then dropped onto the steel or concrete pad. Test motor or device conditioned to ambient temperature. Start motion picture cameras at time of release to record entire sequence of events. If detonation, deflagration or pressure rupture occurs, fragment map shall be prepared indicating distance, direction and weight of both steel and propellant fragments, as well as locations where propellant fragments burned. Record peak blast pressure readings.

33. Conclusions.

Classification for Phase III.

a. Interstate Commerce Commission Class A and/or Military Class 10.

(1) One or more of tests already conducted in Phases I-A, I-B, has resulted in a detonation, independent of results in this phase.

(2) No detonations have occurred in any of the previous tests, but a detonation has occurred during this phase.

(3) No detonations have occurred during any testing (previous phases or this phase); however, it has been determined that the hazard characteristics of the rocket motor or device render it as equivalent to an Interstate Commerce Commission Class A or Military Class 10 rocket motor or device.

b. Interstate Commerce Commission Class B and/or Military Class 2.

(1) Results of either Phase I or II tests place the test item in the category of Military mass-detonating and results of Phase III tests indicate Military fire hazard. Prior to the assignment of the Military fire hazard classification, the Phase III test most closely associated to that test of Phase I or II which was responsible for the assignment of the mass-detonating classification will be repeated a minimum of four (4) times and the results of these additional tests must confirm the fire hazard classification.

(2) No detonations have occurred in Phases I or III, or in the bullet impact or external heat tests of Phase II, and it has been determined that the hazard characteristics of the rocket motor or device are not equivalent to Interstate Commerce Commission Class A and/or Military Class 10.

Phase IV Tests (See paragraph 8c)

34. Introduction.

a. This phase is intended to determine actual hazard characteristics of full scale missiles or subassemblies thereof, upon which quantity-distance requirements can be based. This phase will demonstrate the actual hazards associated with a missile system under the following conditions:

(1) Detonation effects of one motor upon a like motor.

(2) Detonation effects of one stage of a missile on the remaining stages of the same missile.

(3) Effects of warhead detonation on the propulsion stages.

(4) Effects of destruct system on motors.

(5) Effects of external heat on missile.

Upon completion of this phase of testing, sufficient information should be available for the determination of the explosive hazards of the missile as well as quantity-distance requirements for siting launch facilities. It is recommended that a post test infra-red still picture be made of the test area. The altitude from which this picture is taken should be sufficient to include the farthest distance fragments are thrown. It has been found that an infra-red picture will be of considerable value in preparing a fragment map, as all hot fragments as well as locations where propellant fragments burned will readily show up on such a picture.

b. Test equipment required for each test is given under that test.

c. The number and type of samples for each test is specified in each test; however, reject motors may be used for this phase if the reasons for such rejections will not materially affect the test results.

d. The results of these tests are to be given in a narrative report including photographs of test set-up and results, charts or diagrams, and recommendations. Such reports are to be furnished to the Service responsible for test administration, as well as to the distribution list given in paragraph 4e.

35. <u>Detonation Test (two identical Class 10 motors).</u>

a. Equipment.

(1) Motion picture cameras at 16 or 24 frames per second and high speed.

(2) Instrumentation, as available, to measure peak air blast overpressure and temperature along two radial arrays.

(3) Instrumentation to measure chamber pressure.

(4) Test stand or other equipment to restrain item.

(5) One (1) 50/50 pentolite booster 2-inch diameter by 2-inch length and one (1) Engineers Special Electric Blasting Cap (J-2).

b. Test Item.

(1) Two (2) full scale rocket motors with or without packaging as indicated by the condition expected.

c. Test procedure.

The motors will be adequately restrained with separation distance between the motors equal to that indicated by the conditions being reproduced. Instrumentation for measurement of chamber pressure will be installed in each motor. Peak air blast pressure and temperature instrumentation will be installed in two radial arrays at distances determined by calibration test, and at a height compatible with the test set-up. Motion picture coverage will be installed to give coverage from two sides of test set-up. Insert the blasting cap into the pentolite booster. The booster assembly will then be placed inside of the one motor, with the booster in intimate contact with the propellant. Adequate safety precautions will be taken to protect personnel and equipment should a detonation occur. Instrumentation and cameras should be started just prior to initiation of the blasting cap. Should detonation occur, readings from the instrumentation shall be recorded and a fragment map prepared showing material, size and distances projected. Detailed information should be given on the damage sustained by the unprimed motor and its behavior.

36. <u>Detonation Test of Multi-Stage System, Without Warhead, in Which it Has Been Determined that at Least One Stage is Class 10.</u>

a. Equipment.

(1) Motion picture cameras at 16 or 24 frames per second and high speed.

(2) Instrumentation, as available, to measure peak air blast overpressure and temperature along two radial arrays.

(3) Instrumentation to measure chamber pressure.

(4) Test stand or other equipment to restrain item.

(5) One (1) 50/50 pentolite booster 2-inch diameter by 2-inch length and one (1) Engineers Special Electric Blasting Cap (J-2).

b. Test Item.

(1) One (1) system of motor stages.

c. Test Procedure.

Motors will be adequately restrained in the expected storage or assembled configuration. Instrumentation for measurement of chamber pressure will be installed in each motor. Peak air blast pressure and temperature instrumentation will be installed in two radial arrays at distances determined by calibration test, and at a height compatible with the test set-up. Motion picture coverage will be installed to give coverage from two sides of motors. Insert the blasting cap into the pentolite booster. The booster assembly will then be placed inside of the motor which is Class 10 and with the booster in intimate contact with the propellant.

Adequate safety precautions will be taken to protect personnel and equipment, should a detonation occur. Instrumentation and camera shall be started just prior to initiation of the blasting cap. Should detonation occur, readings from the instrumentation shall be recorded and a fragment map prepared showing material, size and distance projected.

37. <u>Detonation Test of Single or Multi-Stage Missiles Complete With Warhead.</u>

a. Equipment.

(1) Motion picture cameras at 16 or 24 frames per second and high speed.

(2) Instrumentation, as available, to measure peak air blast overpressure and temperature along two radial arrays.

(3) Instrumentation to measure chamber pressure and thrust.

(4) Test stand or other equipment to restrain item.

(5) One (1) 50/50 pentolite booster 2-inch diameter by 2-inch length and one (1) Engineers Special Electric Blasting Cap (J-2).

b. Test Item.

(1) One (1) missile motor system with warhead or warhead HE equivalent.

c. Test Procedure.

Missile will be adequately restrained in the expected storage, transportation or tactical configuration. Instrumentation for measurement of chamber pressure will be installed in each motor. Peak air blast pressure and temperature instrumentation will be installed in two radial arrays at distances determined by calibration test, and at a height compatible with the test set-up. Motion picture coverage will be installed to give coverage from two sides of missile. Warhead will be primed using an electric blasting cap. Adequate safety precautions will be taken to protect personnel and equipment should a detonation occur. Instrumentation and cameras shall be started just prior to functioning of the initiator. Should detonation occur, readings from the instrumentation shall be recorded and a fragment map prepared showing material, size and distance projected. Detailed information shall be given on the damage sustained by the unprimed motor and its behavior.

38. If more than one missile will be on a single launcher at the same time or stored together, test 37 above should be repeated using a simulated set-up wherein the missiles are positioned with respect to each other as would normally occur on the launcher or in storage.

39. <u>Destruct System.</u>

a. Equipment.

(1) Destruct system installed on rocket motor.

(2) Test stand or other equipment to restrain item.

(3) Instrumentation to measure chamber pressure.

(4) Instrumentation, of any reliable type, to measure peak blast pressure and temperature along two radial arrays.

(5) 16 or 24 frames per second color motion pictures to record entire duration of test.

b. Test Item.

(1) One (1) full scale rocket motor.

c. Test Procedure.

The destruct system will be installed on the motor. The motor will be adequately restrained, and chamber pressure will be measured. Air blast overpressure will be measured in two radial arrays at distances determined by calibration test, and at a height compatible with the test set-up. Motion picture coverage will be installed to view the motor from opposite sides. The instrumentation and cameras shall be started just prior to destruct initiation, and shall record the entire test sequence. The destruct system will be functioned. If detonation, deflagration or pressure rupture occurs, a fragmentation map shall be prepared indicating distance, direction and weight of both steel and propellant fragments, as well as locations where propellant burned. Record peak blast pressure and temperature readings.

40. External Heat Test of Multi-Stage Systems, Without Warhead.

a. Equipment.

(1) Sufficient lumber or diesel fuel to sustain burning for a minimum of 30 minutes. In determining quantity of lumber or fuel, it must be considered that burning area should be sufficient to heat entire underside of test motor. If lumber is selected for test, it should be soaked sufficiently with fuel so that an adequate portion of lumber can be easily ignited and burning sustained.

(2) Two (2) 2-ounce bags of Class 2 smokeless powder.

(3) Two (2) electric squibs.

(4) Color motion picture cameras of 16 or 24 frames per second to record entire duration of test.

(5) Instrumentation, of any reliable type, to record blast peak pressures along two radial arrays.

(6) Instrumentation, of any reliable type such as paint tape or recording equipment to record peak temperatures at various distances from rocket motor.

(7) Instrumentation, of any reliable type, for recording chamber pressure versus time for the duration of test.

(8) Equipment, as available, for restraining item during test.

b. Test Item.

(1) One (1) complete multi-stage missile without warhead.

c. Test Procedure.

Adequately restrain the test missile in a horizontal attitude and place lumber or fuel of the required quantity beneath the motor. Instrument rocket motors for recording chamber pressures versus time. Position instrumentation for recording air blast overpressure and temperature in two radial arrays at distances determined by calibration test, and at a height compatible with the test set-up. Locate cameras at angles to view aft end and opposite sides of motors. Place fuel or lumber of required quantity beneath rocket motors in a fashion to heat complete underside of motors. Insert squibs into bags of propellant and locate bags so as to initiate burning of fuel or lumber. Start camera and instrumentation at time of initiation of squibs. If a detonation, explosion, or pressure rupture occurs, record peak blast pressure readings and a fragment map shall be prepared indicating distance, direction and weight of both steel and propellant fragments, as well as locations where propellant fragments burned.

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GLOSSARY

1. Deflagration.

A rapid chemical reaction in which the output of heat is sufficient to enable the reaction to proceed and be accelerated without input of heat from another source. Deflagration is a surface phenomenon with the reaction products flowing away from the unreacted material along the surface. Confinement increases pressure, rate of reaction and temperature. The final effect of deflagration under confinement is explosion. (A deflagration may cause a pressure rise in the surrounding air; however, a sonic or supersonic pressure wave will not develop.)

2. Explosion.

A chemical reaction of any chemical compound or mechanical mixture which, when subjected to heat, friction, shock, or other suitable initiation, undergoes a very rapid combustion or decomposition releasing large volumes of highly-heated gases which exert pressures on the surrounding medium. Also, a mechanical reaction in which failure of the container causes the sudden release of pressure from within a pressure vessel, for example, pressure rupture of a steam boiler. Depending on the rate of energy release, an explosion can be categorized as a deflagration, a detonation or pressure rupture.

3. Detonation.

A violent chemical reaction within a chemical compound or mechanical mixture evolving heat and high pressures. A detonation, in contradistinction to deflagration, is the reaction which proceeds through the reacted material toward the unreacted material at a high constant velocity. The velocity of the reaction is supersonic. The result of this chemical reaction is exertion of extremely high pressures on the surrounding medium forming a pressure wave (blast wave) which propagates away from the source at supersonic velocities. A detonation, when the material is located in or near the surface of the ground, is normally characterized by a crater.

4. Fragmentation.

The breaking up of the confining material of a chemical compound or mechanical mixture when an explosion takes place. A deflagration usually reduces the confining material into large pieces which are projected at low velocities whereas a detonation reduces the confining material into small pieces which are projected at high velocities.

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Honolulu, Hawaii
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195 South King Street
Honolulu, Hawaii

London, England
19 Upper Brook Street
London, W. 1, England

Milan, Italy
Via Macedonio Melloni 40
Milano, Italy

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